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GENERAL STUDIES OF THE CHARACTERISTICS AND PROBLEMS ASSOCIATED WITH V/STOL OPERATIONS

by

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GENERAL STUDIES OF THE CHARACTERISTICS AND PROBLEMS ASSOCIATED WITH V/STOL OPERATIONS

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Abstract

From a choice of a wide range of V/STOL applications, this paper is concerned with the civil aircraft aspects. It deals with the main parameters to be studied in resolving VTOL and STOL aircraft characteristics, the weighting of these toward favourable performance and to meeting the proposed certification rules for this form of transport. The part to be played by electronics in all weather operations is also discussed.

Competition from surface transport, and V/STOL airport requirements are referred to, and some general characteristics of the many different aircraft configurations are discussed. Some conclusions are reached suggesting the direction and weighting of future work.

Introduction

V/STOL aircraft principles, engineering solutions, transport and military systems have been the subject of many papers and symposia. There are many experimental aircraft in being and some in service; notably the helicopter family for civil transport, and the Hawker Siddeley Harrier, a fine example of a "fighting" vehicle. Throughout this work a clear feeling can be seen suggesting the real need for an air transport system of this type, but there is certainly no obvious "popular" solution emerging. This paper will, therefore, deal very generally with the subject and discuss some of the controversial aspects as the co-authors see them. It is not intended to propose that a certain type of aeroplane or operational system is the right course to follow. Much more work needs to be done before this could be attempted.

References 1 and 2 are earlier papers by the joint authors on this subject.

	MILITARY STRIKE	MILITARY TRANSPORT	SEARCH RESCUE	CIVIL TRANSPORT	BUSINESS AIRCRAFT
SPEED	HIGH LOW	HIGHEST ECONOMIC	HIGH	HIGHEST ECONOMIC	HIGHEST ECONOMIC
HOVER CAPABILITY	POSSIBLY	NO	YES	NO	NO
MANOEUVERABILITY	MILITARY ACCELERATION	CIVIL ACCELERATION	MILITARY ACCELERATION	CIVIL ACCELERATION	CIVIL ACCELERATION
NOISE				COMMUNITY ACCEPTABLE	COMMUNITY ACCEPTABLE
ALL WEATHER CAPABILITY	YES	YES	YES	YES	YES
AIRPORT FACILITIES	BUSH TACTICAL	BUSH TACTICAL	NONE	MINIMUM ECONOMIC	MINIMUM ECONOMIC
COST OF SYSTEM	NECESSITY LIMITED	NECESSITY LIMITED	NECESSITY LIMITED	FARE LEVEL LIMITED	FARE LEVEL LIMITED

FIGURE 1 CHARACTERISTICS OF V/STOL SYSTEMS

The principal characteristics of five V/STOL applications are shown in Figure 1. The comments are abbreviated and therefore very general. But sufficient indication is given to show that the selection of airframe, powerplant and lifting system varies considerably with the application. Simplifying; military systems are less subject to noise restrictions and cost prohibition, but have more critical "Airport" conditions to meet than the civil systems. Only the Search and Rescue operation needs a hover capability, although the military strike aircraft could benefit from this. All systems need an all weather capability and all need the highest speed compatible with their overall operating economics. The Military Strike, and Search and Rescue systems need a large forward speed range; high speed to get to the attack or rescue area and low speed or hover for target recognition or rescue.

To comment on all possible V/STOL uses is outside the scope of this paper, hence it will examine only the application of V/STOL techniques to civil transports.

The Transport System

History

The earliest communities of man were founded where the three essential needs for survival - food, clothing and shelter - could be satisfied by unaided human muscle power.

The evolution of transport began when primitive man discovered that he could drag more than he could carry; that many animals had a greater carrying capacity than his own; that heavy weights could be supported on and moved in water; and that the use of a round log (later the wheel) would aid his own efforts. Movement of goods now became possible and the earliest cities were formed at transport nodes. As ships grew bigger and faster the known world expanded and ports became centres of great activity.

The next step was the provision of efficient local transport between the primary nodes which in turn generated new centres of population and led to the establishment of tracks and roads. The personal beast of burden gave way first to the stage coach and later to the railways, linking substantially the same centres.

The arrival of aircraft on the transport scene added a third dimension and extra degree of flexibility. Initially the limited capacity meant that although the aircraft flew between points near to existing centres of population it could have little effect on the established way of life.

The advent of the large subsonic jet has altered this and long haul air transport is now creating its own nodes just as the ship had done many centuries before.

The Problem.

The first problem facing the transport planners of the world today is that of linking the established centres of population with the new long haul nodes. In some cases it may not prove economic to forge this link, and, as has happend in the past, important cities established in an outdated transport network may suffer and ultimately disappear. The second problem is transport between existing communities.

An obvious first step is to consider the Intercity and Community Service Air Transport systems against existing surface transport, the degree to which each are complementary and the extent to which existing terminal facilities - rail yards, wharfs, etc. - can be integrated into the new system. Alongside this, one must anticipate competitive development of rail, motorway and hovertrack transports. Existing trains can handle 40 - 60,000 passengers per hour on one track, and a motorway can handle 9,000 passengers per hour, or in city streets, 4,000 passengers per hour. The mind boggles at the thought of 500 V/STOL aircraft leaving a city per hour.

Clearly the field of opportunity for aircraft operating in an Intercity and Community Service environment must be defined more closely.

The Opportunity

There would appear to be two gaps in the existing and projected transport system. One is immediately beyond the passenger refusal distance of about 400 yards beyond which he will not walk. This clearly is no case for aircraft.

The second and more interesting gap occurs in the grey area where existing surface transport (either public or private) takes too long and present day air travel is or would be inefficient.

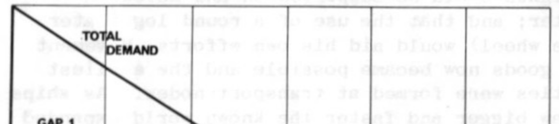


FIGURE 2 TRANSPORT CAPACITY OF EXISTING SYSTEMS

Figure 2 (Reference 3) is an example of the distribution of transport capacity of existing systems against trip distance. This picture will vary somewhat with location but the figures come out somewhere between 20 and 300 miles. At one end of the scale this takes in the city centre to major airport journey, examples of which are shown in Figure 3, and the other end coincides with the peak density of current short haul aircraft operations.

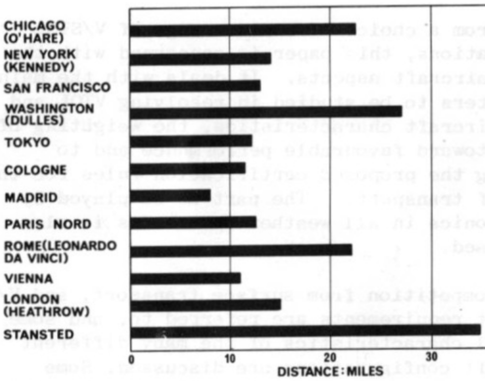


FIGURE 3 DISTANCES FROM CITY CENTRES OF TYPICAL MAJOR AIRPORTS

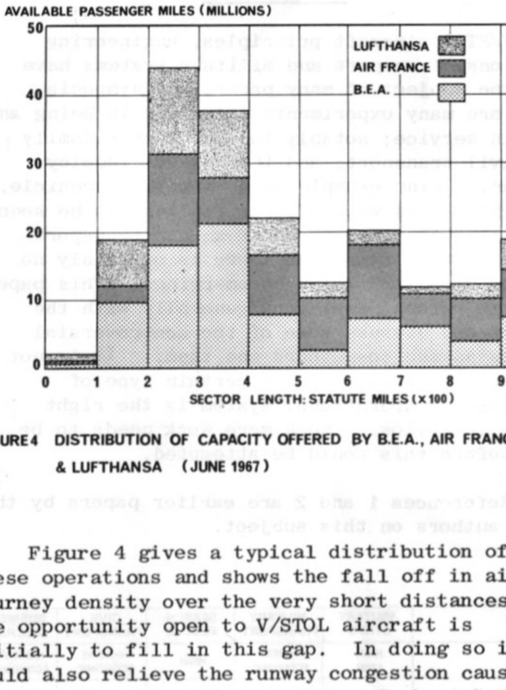


FIGURE 4 DISTRIBUTION OF CAPACITY OFFERED BY B.E.A., AIR FRANCE & LUFTHANSA (JUNE 1967)

Figure 4 gives a typical distribution of these operations and shows the fall off in aircraft journey density over the very short distances. The opportunity open to V/STOL aircraft is initially to fill in this gap. In doing so it could also relieve the runway congestion caused by the high frequency of operations of short haul aircraft by taking over some of their operations, thereby allowing the latter to increase its average operating stage length and improve its economy. The shorter runway is a great advantage where land is at a premium.

The Competition

In order to arrive at some realistic requirements for V/STOL aircraft operating in an intercity and community service environment it is necessary to anticipate and evaluate the competition. Only a summary of this is possible in this paper.

Figures 5 and 6 show this competition in terms of trip time and distance (Reference 4) and operating cost.

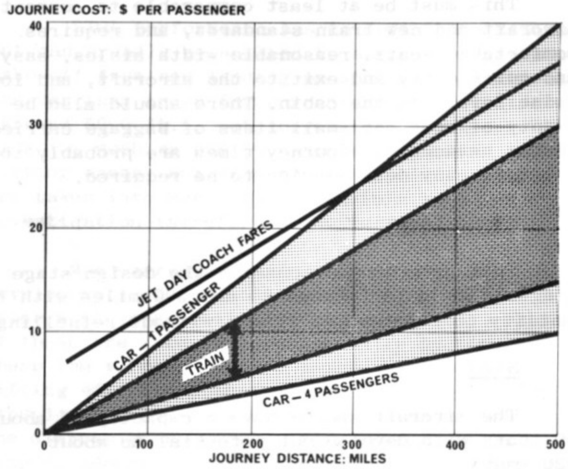


FIGURE 5 JOURNEY COST V. DISTANCE FOR TYPICAL SYSTEMS

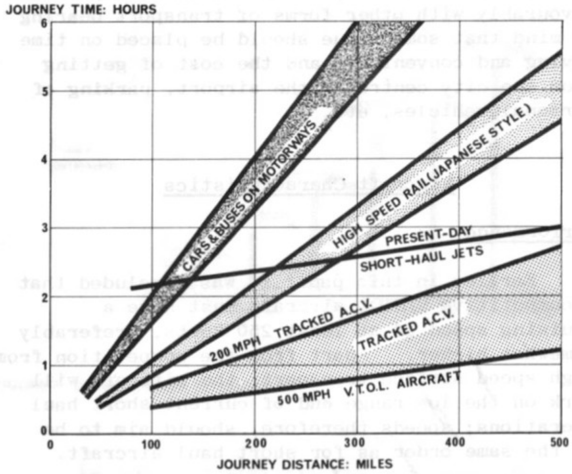


FIGURE 6 CITY CENTRE—CITY CENTRE JOURNEY TIME V. DISTANCE FOR TYPICAL SYSTEMS

Competitive characteristics of some of these follow:-

Trains

Train fares are reasonably cheap, although the true cost of trains is somewhat higher because most railway systems operate at a loss. Block speeds are fairly high, and will improve as new systems are brought into use, e.g. the British Rail electrification scheme, and the Japanese Tokaido Railway. The track and equipment costs of these new systems are, however, very high and higher fares will need to be charged if the initial investment is to be recovered.

On trunk routes trains are comfortable and the passenger can relax, work or have a meal during the journey. They provide a high capacity enabling large numbers of commuters to be brought into the city centre. For example an eight coach train carries up to 1,000 people, the British Rail Southern Region bring into London up to 200,000 people an hour in peak periods. No other current transport system can equal this. Trains also provide a reasonable service in conditions of poor visibility.

Their disadvantages lie in the time lost getting to and from the station, and waiting for and changing trains. The places that one can reach by train are limited by an expensive track system, also block times become rather long for stage distances over 200 - 300 miles.

Tracked Air Cushion Vehicles.

This transport system is likely to form the nucleus of future high speed tracked transport. Because of its single degree of freedom and need of expensive tracks its use will most likely be confined to major airport to major city centres and in certain city pair links where the traffic density is extremely high. Under these high utilization conditions the fare level should be low.

Cars

The motor car is mainly used for short distances, i.e. 1 - 20 miles or over 100 miles if the road system is good. It is reasonably cheap. It is available at any time and it takes one from the point of departure to the destination without changing, and the consequent loss of time. Baggage is easily carried and if the road system is good, block speeds are reasonably high.

The disadvantages are that traffic congestion and adverse weather can considerably reduce block speed; parking can also be a problem at one's destination; the driver cannot relax or work during the journey. This last problem could be alleviated by some form of automatic guidance system on motorways which would also assist in conditions of poor visibility.

Roads of a motorway standard, however, are expensive, costing about $3 million/mile in open countryside and rising over $15 million / mile in urban areas. However, the motor car is a formidable competitor to any short haul transport system where the road system is good.

Buses

The main advantage of the bus is its cheapness, versatility and frequency of service, and its good utilisation of road space in urban areas. Block speeds, however, tend to be rather low.

Short Haul Conventional Aircraft

Modern jet aircraft provide fast, comfortable travel between airports but the time required to get from the city centre or place of residence tends to nullify the aircraft speed advantage over distances less than about 200 - 300 miles, and fares tend to be higher than those charged by other forms of transport.

Airports tend to be poorly served by public transport which tends to be a radial system into and out of the city centre. Thus in many cases to reach an airport one has first to travel into the city centre, change transport and travel out again to the airport situated perhaps more than 20 miles away. Aircraft at the moment are badly affected by conditions of poor visibility although the advent of automatic landing systems will considerably alleviate this problem.

Aircraft have the advantage of not needing an expensive track system so that the point served, and the frequency, can be changed with the changing market demands, without requiring new track or under-utilising existing track.

Since the air transport business cannot aim at swallowing the commuter market and it is unlikely to compete with high speed rail or tracked air cushion vehicles on the very high density airport to city, and city to city links, it would seem reasonable to attempt to relate the capacity of any V/STOL aircraft to that of the trunk line aircraft generating the traffic.

From the many essays written on the subject throughout the air-transport world, it would appear that arrival passengers at international and major air terminals proceed onward in about three directions. This trend, if real, would suggest a V/STOL feeder/intercity aircraft should have about one third of the capacity of trunk line transports or approximately 60 seats at today's conditions stretching to 100 to 120 seats following the introduction of the large jumbo jets.

The Requirement.

From the foregoing a V/STOL community service aircraft requirement can be formed. To put this in simple terms in relation to the scope of this paper, the aircraft require the following capabilities.

Speed

To improve on existing and compete with new surface transport, and to integrate with existing short haul operations, the cruise speed should be at least 250 knots, preferably higher. A frequent and regular service is also required in order that the advantage of high cruising speed is not lost.

Take-off and Landing Performance

This should be such that airports can be constructed in or skirting built-up areas and be close to, or capable of using, the amenities of existing transport systems.

Noise

The noise generated by these aircraft must be compatible with the existing environment.

Safety

The aircraft must be at least as safe as the best surface transport system, as far as the passengers are concerned. As far as the inhabitants of the city centre are concerned, the probability of crashing into a built-up area due to under or overshooting the runway or due to structural or system failure must be very low indeed, probably better than 10^{-7}. This is considerably better than current standards.

Comfort

This must be at least comparable to current aircraft and new train standards, and requires comfortable seats, reasonable width aisles, easy and quick entry and exit to the aircraft, and low noise levels in the cabin. There should also be plenty of room for small items of baggage carried by the passenger. Journey times are probably too short for any meal service to be required.

Stage Length

From preceding discussion the design stage length should be between 20 and 300 miles with the ability to fly several stages without refuelling.

Size

The aircraft should have a capacity of about 60 seats with development potential to about 120 seats.

Economics

The fare to the passenger should compare favourably with other forms of transport bearing in mind that some value should be placed on time saving and convenience and the cost of getting from the city centre to the airport, parking of personal vehicles, etc.

Aircraft Characteristics

Performance

Earlier in this paper it was concluded that a competitive V/STOL aircraft must have a cruising speed of at least 250 knots, preferably somewhat higher. Apart from the competition from high speed surface transport, the aircraft will work on the low range end of current short haul operations; speeds therefore, should aim to be of the same order as for short haul aircraft.

Thus from the speed point of view the general airframe characteristics need to be similar to those of current short haul aircraft. These characteristics have been evolved from a long research and development process, the benefits of which should be retained as far as possible consistent with the new environment. Of these characteristics wing loading and power loading are the most significant. High speed short haul aircraft need a relatively high wing loading in the order of 100 lb/ft^2, with high lift devices required to achieve acceptable airfield performance. Power loading (T/W) of the order of 0.25 is required to meet the airfield performance with acceptable safety margins.

The aircraft under discussion in this paper must operate from much shorter landing strips, tending to zero length in an ideal situation. To achieve these conditions the aircraft characteristics must change toward lower wing loading or more installed thrust, or a combination of both, leading in turn to a more costly airframe system. A delicate balance of conditions thereby exists. To examine some of these STOL and VTOL are now considered separately.

STOL Characteristics

General

STOL performance has no definitive dimension but can broadly be applied to aircraft capable of take-off from and landing on strips substantially shorter than those for current short haul aircraft (around 5000 ft.), but longer than practical VTO pads (as much as 500 ft. when manoeuvering, space, parking areas, building proximity limits, etc., are taken into account). A sensible band for investigation therefore might be 500 - 3,000 ft.

Many aerodynamic and engineering developments of the conventional wing are available which will improve its lifting capability. Some of these are shown diagrammatically in Figure 7 where the vertical bar represents the relative lifting efficiency when the other conditions of wing loading and forward speed are held constant. The diagram shows various flap configurations, wing incidence changes, and deflected slipstream systems; the installed power is of conventional order and not orientated to thrust lift directly.

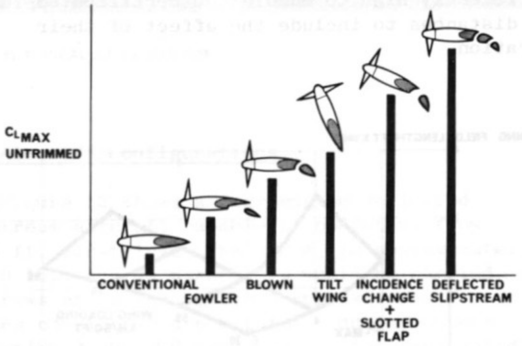


FIGURE 7 DEVELOPMENT OF WING LIFT

In order to simplify the approach, STOL fixed wing aircraft only are considered here.

STOL Aircraft Take-Off Performance.

Figure 8 shows some generalised curves of the effect of wing lift (Wing Loading/CL max) and power loading (thrust/weight) on take-off distance. The thrust used in the power loading is assumed to be the mean power during the take-off run. The take-off distances are the all-engines take-off distance to clear 35 ft. multiplied by 1.15 It is assumed that these STOL aircraft are four engined. CL max is the CL appropriate to the minimum demonstrated flying speed (V min.) with the critical powerplant inoperative. The aircraft is assumed to take-off at 1.2 V min. or V min. + 20 knots whichever is the greater.

Using these rules it can be seen that to achieve distances less than about 1,500 ft., fairly high thrust /weight ratios are required, plus

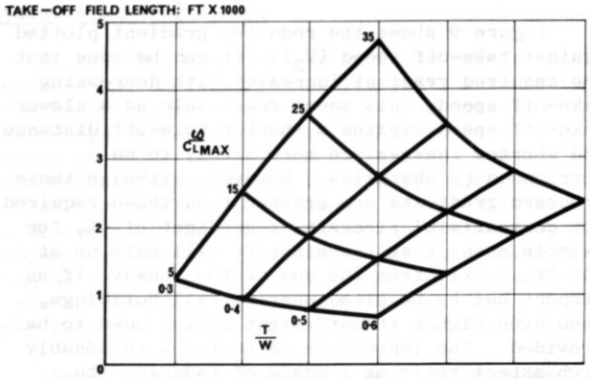


FIGURE 8 EFFECT OF LIFT AND POWER LOADING ON TAKE-OFF DISTANCE

a combination of low wing loading and high CL max. For example, a 1,500 ft. take-off would require a $T/_W = 0.4$ and a W/C_L max. = 10 which implies a C/L max. of 5.0 with a wing loading of 50 lb/sq.ft. This order of wing loading is considerably lower than current short range jet aircraft, (the BAC One-Eleven has a wing loading of about 90 lb/sq.ft.), and a little lower than current propeller turbine aircraft, (the Fokker Friendship has a wing loading of about 58 lb/sq.ft.). Thus there would be a weight penalty for the increased wing area as well as the penalty for the high thrust/weight ratio, a T/W = 0.4 being considerably higher than that for conventional aircraft. Shorter take-off distances can be obtained by ignoring the possibility of an engine failure or by having a lower margin between Vmin and take-off speed. By these means and by using a very low wing loading coupled with an efficient flap system several types of small aircraft have demonstrated very short take-off distances during trials associated with experimental operations from city areas. However, it seems doubtful whether a larger aircraft, with its higher wing loading, could carry out safe and regular civil operations in all weather conditions with margins much less than those suggested above.

The proposed FAA V/STOL tentative airworthiness standards indicate that a four engined STOL aircraft should have the following climb gradients after take-off with the critical powerplant inoperative:- 2.9% or 250 ft/minute, whichever is greater, with the gear extended, and 3% or 300 ft/minute with the gear retracted.

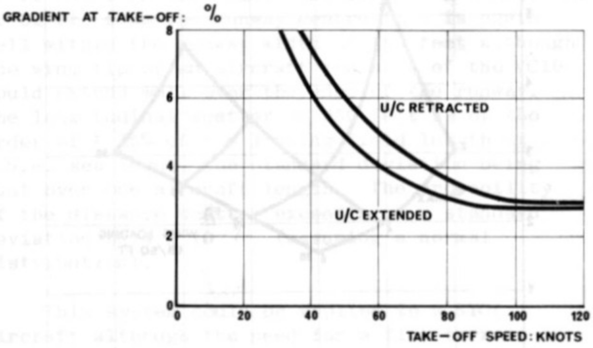


FIGURE 9 EFFECT OF TAKE-OFF SPEED ON REQUIRED GRADIENT AT TAKE-OFF

Figure 9 shows the required gradient plotted against take-off speed (V_2). It can be seen that the required gradient increases with decreasing take-off speed, this seems reasonable as a slower take-off speed implies a shorter take-off distance and shorter runways are more likely to be surrounded by obstacles. However, although these proposed gradients are greater than those required for conventional aircraft, a gradient of 4%, for example,means that the aircraft will only be at 200 ft. a mile from the end of the runway. If an airport has to be sited near to tall buildings, then even higher thrust/weight ratios need to be provided. The importance of having a reasonably high aspect ratio as a means of reducing the power loading to meet the required climb gradients is illustrated in Figure 10; this is especially so if high lift coefficients are to be generated.

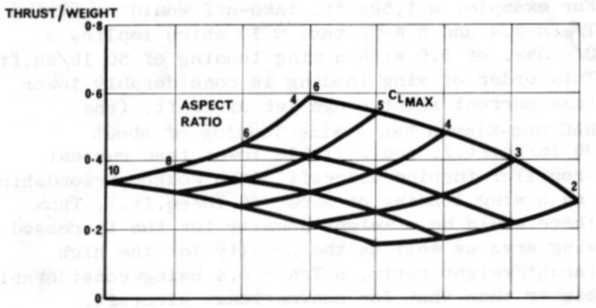


FIGURE 10 REQUIRED THRUST/WEIGHT RATIO TO MEET GRADIENT REQUIREMENTS WITH ONE ENGINE INOPERATIVE

As a further example of the importance of span, reference 5 shows that the take-off distance can actually increase with increasing lift coefficient due to the very high induced drag for wings of low aspect ratio.

STOL Aircraft Landing Performance

Figure 11 shows some generalised curves of the effect of wing loading and C_L max. (based on V min. as previously defined) on landing distance from 35 feet using wheel brakes only.

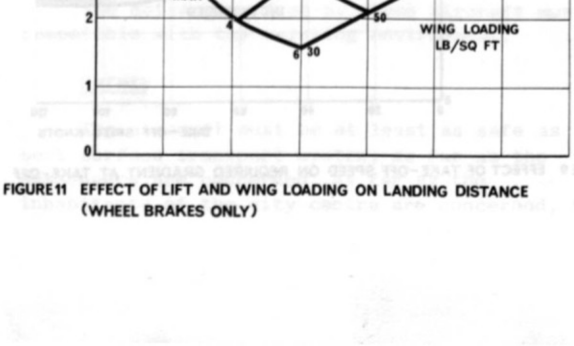


FIGURE 11 EFFECT OF LIFT AND WING LOADING ON LANDING DISTANCE (WHEEL BRAKES ONLY)

The following rules have been assumed in order to calculate the landing distances. The aircraft is assumed to approach at 1.15 x the normal approach speed, where the normal approach speed is 1.3 Vmin. or Vmin. + 20 knots, whichever is the greater. The rate of descent at 35 feet is assumed to be 500 feet/minute and is reduced to 180 feet/minute over the last 10 feet of height. The runway surface is assumed to be wet with a factor as defined by BCAR with a braking efficiency of 85%. The distance calculated is then factored by 1.1 to obtain the field length. It is considered that although shorter landing distances could be demonstrated the certificated landing distances must include the above factors to allow for variations in pilot technique, runway conditions, wind gradient, etc. There will also be variations in landing distance due to different aircraft weights and ambient conditions which will have to be taken into account in determining the payload which can be carried over a given sector.

Figure 12 shows the effect of assuming a constant deceleration of 0.5g which is probably about the limit for normal passenger comfort. Means must be provided for selecting reverse thrust and applying the wheel brakes at touch down. The means for doing this must be of such reliability that there is no likelihood of inadvertent selection during flight, and the probability of operation at touchdown is sufficiently high to enable the certificated landing distances to include the effect of their operation.

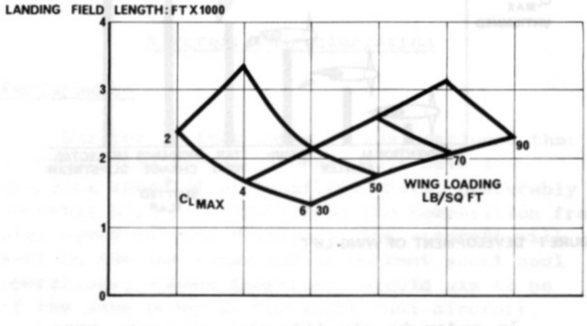


FIGURE 12 EFFECT OF LIFT AND WING LOADING ON LANDING DISTANCE (0·5G DECELERATION DURING GROUND ROLL)

As can be seen from Figures 11 and 12, wing loadings of 30 - 50 lb/sq.ft., and C_L max's of 4 - 6, combined with the means of obtaining a deceleration of 0.5g, are required to achieve landing distances of the order of 1,500 feet When landing distances are of the order of 1,500 feet, the largest part of this distance is the airborne distance and hence if significant improvements are to be made, ways must be found of reducing this part of the landing distance. For example, if the descent rate of 500 ft/min. were maintained to touchdown instead of reducing to 180 feet/minute for the last 10 feet of height, about 400 feet could be saved in a 1,500 feet landing distance. A 500 ft/min. descent rate is 8.3 ft/sec., which is close to the normal design vertical descent velocity of about 10 ft/sec. for undercarriages on conventional aircraft. The average touchdown velocity for conventional aircraft is about 2 ft/sec. with a 'g' increment of about 0.2 depending on the type of undercarriage. Thus it would seem that if this technique is to be used the undercarriage stroke would have to be doubled and the 'g' increment considerably increased. Also the design vertical velocity for the undercarriage would have to be increased to 16 - 18 ft/sec., which is similar to that for naval deck landing aircraft. Thus further study is required in the design of long stroke undercarriages and in deciding what is the maximum vertical acceleration acceptable to the passenger.

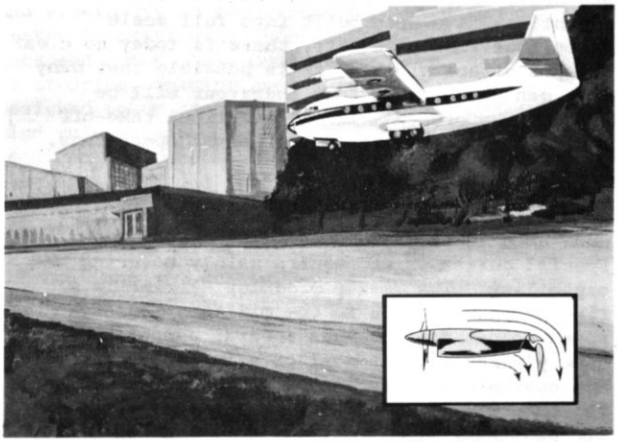


FIGURE 13 TYPICAL S.T.O.L. SYSTEM

STOL Aircraft Configurations

Figure 13 shows a four engine deflected slipstream aircraft capable of operating from 1,500 ft. airstrips. The A.U.W. is approximately 45,000 lb., and 45 passengers would be carried in 9 rows at 34 inch pitch 5 abreast. The engines considered are Bristol Siddeley Gnomes developing 1,400 SHP each and are interconnected by a shaft running through the leading edge of the wing. Thus if an engine fails all four propellers continue turning driven by the other three engines and maintaining the slipstream over the whole wing span. Studies indicate that this type of aircraft is likely to give the lowest operating cost of any of the many V/STOL configurations (this is also confirmed by the NASA Short Haul Transport study, Reference 6). The practicability of this scheme has been confirmed by the Breguet 941, several models of which have completed many short take-offs and landings in operational conditions.

In an attempt to lower the noise levels still further, studies have been carried out on an aircraft with two large diameter propellers, each with a diameter of 36 ft. and driven by two Bristol Siddeley Gnome engines coupled together to give an output of 2,800 SHP, thus giving a lower disc loading. In order to provide the necessary clearance between propeller and ground, the wing is arranged to tilt through 15°.

Automatic Landing System

If the STOL aircraft system is to have a departure and arrival reliability similar to that of surface transport systems then an automatic landing system is required to enable it to operate in conditions of poor visibility. Also the automatic landing system, with its more accurate approach path and speed, may provide a way of reducing the required landing distance by eliminating some of the factors. As an example of an automatic landing system and the accuracy it can achieve, the system developed for the Super VC10 is briefly described.

The aircraft follows the I.L.S. glide slope and localizer down to 100 ft., at which point the I.L.S. glide slope is becoming inaccurate. So it is disconnected, the azimuth channel being left 'in', and the autopilot then holds the aircraft attitude constant with the auto-throttles holding the speed constant, thus maintaining approximately the same glide slope as the I.L.S. At about 50 ft. the throttles are closed and a programmed flare is initiated, the radio altimeter providing height reference, to give a touch down velocity of 2 - 3 ft/sec. At the moment the pilot corrects for drift at touchdown but the system is to be developed to enable this to be done automatically. The system requires that the runway width must be at least 150 feet and that the terrain over which the aircraft passes when it is at 60 feet or less must be flat with a maximum deviation of ±2.5 ft. The following table indicates the measured accuracy obtained with the system:-

	MEAN	STANDARD DEVIATION	5 x STANDARD DEVIATION
VERTICAL VELOCITY AT TOUCH DOWN (FT/SEC)	2·8	0·87	*7·1
LATERAL DISPLACEMENT FROM RUNWAY CENTRE LINE (FT)	0	6·3	31
LONGITUDINAL SCATTER FROM I.L.S. REFERENCE POINT (FT)	1002	190	950

*MEAN + 5 x STANDARD DEVIATION

FIGURE 14 ACCURACY OBTAINED WITH SUPER VC10 AUTOMATIC LANDING SYSTEM

As can be seen from the above table, the vertical velocity of 7.1 ft/sec. is well within the design value for the undercarriage which is 11 ft /sec. on the VC10. The lateral displacement of 31 ft. from the runway centre line is again well within the runway width of 150 feet although the wing tip of an aircraft the size of the VC10 would extend well over the edge of the runway. The longitudinal scatter of 950 feet is of the order of ± 15% of the landing field length at I.S.A. sea level, the standard deviation being just over one aircraft length. The probability of the distance scatter exceeding 5 x standard deviation is 4×10^{-7} (assuming a normal distribution).

This system could be applied to a STOL aircraft although the need for a flat terrain below the approach path may present some difficulties at certain airfields. One would expect that the lower approach speed of a STOL aircraft would reduce the longitudinal scatter although any wind gradient effect, which is one source of error, would be greater on a slow approach speed aircraft. However, one way of obtaining a large improvement in accuracy is to eliminate or partially eliminate the flare. This would require, as suggested previously, designing the aircraft undercarriage for much larger vertical velocities. Partially eliminating the flare would also reduce the length of flat terrain required because the radio altimeter would be used at an altitude lower than the 50 ft. for the VC10.

Thus using an automatic landing system, it is suggested that the landing field length could be defined as follows:-

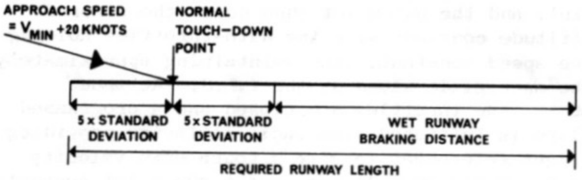


FIGURE 15 LANDING FIELD LENGTH USING AN AUTOMATIC LANDING SYSTEM

The braking distance would be based on the normal approach speed instead of a factored speed, as suggested previously, because the automatic system can hold the airspeed to within ± 3 knots of the required value. Thus the distance from 35 ft. would be ignored and the approach angle determined by considerations of aircraft drag and handling, obstacle clearance, noise, etc.

The development of an automatic landing system requires a considerable amount of flying to enable the accuracy and failure rate of the system to be determined to a sufficient confidence level for civil operations. For example the VC10 system required about 1100 landings for the system to be cleared for use in Cat. I conditions when carrying fare paying passengers, and probably will require a further several hundred landings in airline service to enable it to be cleared for operations under Categories II and IIIA conditions.

VTOL Characteristics

General

The STOL approach developed in this paper has been basically the adaptation and improvement of the airfield characteristics of the classical aeroplane, by development of high lift on the fixed wing and increase in T/W ratio. VTO arrangements, however, require a new approach to the airframe layout. The conventional wing is of no use for take-off and landing at zero forward speed and the "wing" required on which to cruise must therefore be augmented or replaced by some other form of lift. The vertical component of any force used to generate lift must exceed the maximum weight of the aircraft and must achieve a high order of reliability equal to the integrity of the wing structure.

An aircraft to meet these basic conditions is, relative to a conventional civil aircraft, going to contain a much larger powerplant as a proportion of its weight, or more complex mechanical parts, or a combination of both. This situation is one which must make the achievement of competitive D.O.C. figures a tremendous task, and it is for this reason, no doubt, that we see no vertical take-off civil aircraft other than helicopters in general service today, the exceptions being rather specialist in nature - emergency, V.I.P. or air-taxi work.

Many years have elapsed since the first experimental test beds came into being, the Rolls-Royce Flying Bedstead in 1953, and the many early flying models such as the American XFV-1 and XFY-1 in about 1947, and many different inventions have been built into full scale aeroplanes. Despite this, there is today no clear line of attack visible; it is possible that many more man years of patient endeavour will be required before the "ideal" (vertical take-off and landing) is available for civil operations.

The helicopter has been the subject of considerable development and is second to none when used in its unique roles of rescue and special duties which require mainly hovering capability. The Hawker Siddeley Harrier is a fine example of VTOL in the military and high speed combat field. Such special purpose aircraft have yielded a great deal of valuable scientific and engineering data in the V/STOL field, on which the future will be built. Helicopters are used for passenger transport, but in a limited field, and it is fair to say that at the current state of the art, neither of these systems are yet ready for competitive operational VTOL civil aircraft.

It is not intended in this paper to go into technical details of possible VTOL types but a few general remarks follow.

VTOL Configurations

Helicopter

This type is currently the only VTOL aircraft in commercial service. Its advantages are good hovering performance and low installed power because of low disc loading; this feature makes it less noisy than other forms of VTOL aircraft. Disadvantages are, its inability to achieve high cruise speeds due to the problems of retreating blade stall and Mach number effects on the advancing blade as the forward speed increases, and maintenance cost of the rotor system and gearboxes. Part of the reason why current helicopter services tend to be unprofitable is due to their small size, the largest commercial helicopter having about 25 seats; others are the frequent replacement of fatigue critical parts and the frequent maintenance of the rotor system to achieve the required reliability levels.

Various schemes have been proposed for reducing the complexity of the rotor system, notably the Lockheed rigid rotor concept and the British NGTE circulation controlled rotor.

Development of rotor aircraft in the VTOL field will almost certainly figure as a serious competitor, especially as mechanical complication gets reduced.

Compound Helicopter.

One way of alleviating the advancing blade problem is to slow down the rotational speed of the rotor. Fixed wings and an auxilliary propulsion system are then required to compensate for the loss of lift and forward thrust. This method allows a fairly small increase in forward speed, typically from under 200 knots to perhaps nearly 250 knots, because the area of reverse flow on the retreating blade is soon increased and with it the general asymmetry. The speed on the compound helicopter could be further increased by stopping and folding the rotor and either parking it in the line of flight or retracting and stowing it in the aircraft. Wind tunnel tests, in particular those carried out on the Lockheed rotor, have demonstrated the feasibility of stopping, folding and starting properly designed rotor systems at considerable relative wind velocities. However, much more work is required to overcome the many problems involved. Stowing the folded rotors in the fuselage is likely to give rise to severe problems from the structural, volume, weight and reliability points of view. These penalties will increase the cost and reduce the payload which will have to be offset by the increased cruising speed and hence greater productivity.

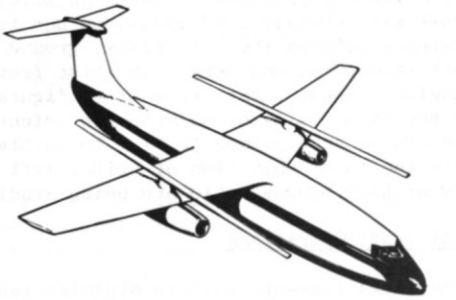
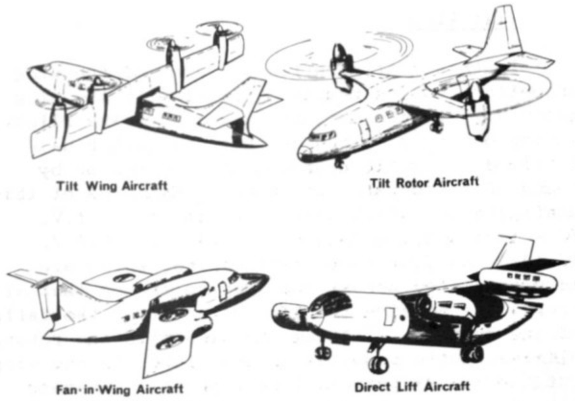


FIGURE 16 CIRCULATION-CONTROLLED ROTOR AIRCRAFT

As an alternative to stowing the rotor, the concept of the fixed wing stopped rotor has been proposed, notably by the Hughes Aircraft Company, who use a rotor with a high solidity inner portion which serves as the primary lifting surface. Another proposal is the NGTE circulation controlled rotor which is a two bladed rotor of circular/elliptical cross-section and having sufficient rigidity to enable it to be parked in line of flight. Air is blown tangentially downward through spanwise slots in the upper "trailing edge" of the rotor, to induce a circulation of the air flow. The rotor section thus behaves as an aerofoil section and produces lift. Figure 16 shows an artist's impression of such an aircraft.

Figure 17 shows 4 other possible concepts giving VTOL capability.



Tilt Wing Aircraft

Tilt Rotor Aircraft

Fan-in-Wing Aircraft

Direct Lift Aircraft

FIGURE 17 TYPES OF V/STOL AIRCRAFT

Tilt Rotor

As an alternative to stopping the rotor, its axis can be tilted forward through 90° and used as a means for generating forward thrust. These rotors or propellers, which normally are located at or near the wing tips, tilt during the transition cycle while the wing remains fixed relative to the fuselage. During hovering, control is usually obtained solely from the rotors, i.e. cyclic for pitch, differential collective for roll, and differential cyclic for directional control. During transition a mixing of controls is required. Typical configurations are powered by four turboshaft engines mounted in pairs at each wing tip and driving two large propeller/rotors through individual overrunning clutches. The rotors are interconnected across the wing by a high speed shaft system which is used to supply equal power to each rotor during normal and emergency (engine failure) operations. The engine nacelles are rotated by gear trains driven by hydraulic motors, the reliability of which must be such that probability of failure is very low indeed (10^{-7}) because the large diameter of the rotors means that a normal landing cannot be made if the rotors are tilted through less than about 45° because of ground clearance problems. The main aerodynamic problems appear to be due to (a) the fixed horizontal position of the wing producing considerable downloads during hovering and transition and (b) aerodynamic characteristics, e.g. efficiency, sensitivity to gusts, etc., and aeroelastic instability of the rotors at high forward speeds, especially when low disc loadings are used. However, low disc loading will mean relatively low noise levels and also may mean that an auto-rotational landing could be made after complete power failure. Further advantages of this scheme are: no problems of stowing or folding the rotor during cruising flight; no auxiliary propulsion system; and fuel can be carried in the wings in the normal manner.

Other tilt rotor configurations use two wings with a rotor on each wing tip; examples of this are the Curtiss Wright X-19, and the Bell X22A which has shrouded rotors. These schemes have higher disc loadings and hence tend to be more noisy and the four rotors make the system more complex. The smaller size of rotor, however, means that good STOL performance is available, at overload conditions, with the rotor thrust line either horizontal or at a small angle.

Tilt Wing

In this configuration the axes of the wing propellers/rotors remain parallel with the wing chord during both horizontal and hovering flight. During hovering, pitch control can either be obtained by cyclic change of the rotors or by means of a separate tail rotor. Examples of this configuration which have flown are the L.T.V. XC - 142A and the Canadair CL-84. The L.T.V. XC-142A has four turboshaft engines which are interconnected across the wing to ensure that all propellers receive the same power after the failure of one engine. Tilting the wing with the rotors eliminates the problems of down loads on the wing but the new slipstream direction will generate lift forces on the wing. Large flaps deflecting in the appropriate direction may alleviate these unfavourable propeller-wing interference effects and may also be used differentially for yaw control of the aircraft. A four engine configuration tends to imply higher disc loadings and hence more noise; on the other hand the small rotors mean that the aircraft can perform a short take-off in a conventional manner with the wing nearly horizontal at higher all up weights. As with all configurations using the same rotor for vertical and horizontal flight there is the problem of achieving high rotor efficiency in both flight regimes.

Fan in Wing

This configuration provides a means of improving the cruising performance of a VTOL aircraft; the relatively clean aerodynamic design enables cruise Mach numbers of the order of 0.8 to be achieved. Typical configurations have two lifting fans buried in each wing, driven by tip turbines powered by the gas generators of the main propulsion system. Cross couplings of gas generators and tip turbines prevent complete loss of fan lift after a single engine failure. Control in pitch is provided by a lifting fan in the aircraft nose, lateral control is by differential movement of the vanes directing the exhaust of each fan, rolling control is by differential lift of each wing fan. The lifting fans occupy a large area of the wing and a nearly constant chord wing is required if all fans are the same size with no wasted wing space. Considerable wing volume is also required for the interconnecting duct system. These hot ducts must pass through the pressurised fuselage to feed the fan in the nose of the aircraft and can present problems from the safety point of view. Thus there tends to be a weight penalty due to the wing area being larger than that required for cruise, and a fuel capacity problem due to lack of volume in the wing. The complex arrangement of hot ducts, fans and propulsion engines seems likely to give rise to considerable maintenance. Fan lift will be affected by interference of the fan efflux with the ground and surrounding aircraft structure. In the configuration the potentially high productivity will have to offset the cost of overcoming these problems.

Jet Lift

There are three main types of jet lift aircraft.

1. Those which vector the thrust of the propulsion engine or engines to give either horizontal thrust or vertical lift, e.g. Hawker Siddeley Harrier.

2. Those which use separate lift and propulsion engines, e.g. Dassault Mirage IIIV.

3. A combination of (1) and (2), e.g. Dornier DO. 31E.

These examples are all military aircraft but their basic principles are applicable to civil types.

Scheme 1 requires that the propulsion engines provide a thrust greater than the weight of the aircraft, and this could be in excess of the equivalent installed thrust for cruising flight of a conventional civil aircraft by a factor of at least 3 : 1. Schemes 2 and 3 are more favourable for civil aircraft. A large number of lift engines (e.g. Rolls Royce RB.162 engines) would be employed so that safe flight can be maintained after the failure of one or perhaps two engines. These lift engines can be mounted in a large pod at or near each wing tip, so that throttling and deflection of the exhaust provides a means for controlling the aircraft. The main problems are installation and control of a large number of lift engines without undue weight penalty and drag; high fuel consumption which limits hovering time; high downwash velocities which can present problems at the VTOL site; loss of thrust with certain configurations due to interference between the jet efflux, ground and aircraft structure; and very high noise from the lift engines. Again, this type of configuration can be aerodynamically clean with the potential of high cruise Mach number (0.8). To partially overcome the major objection of noise, lift engines of high bypass ratio are being studied.

VTOL Aircraft Operations

The ideal take-off path to minimise the effects of noise and provide maximum obstacle clearance is one where the aircraft climbs vertically to, say, 1,000 ft., and then accelerates along a shallow climbing angle to cruising speed. However this has several drawbacks:-

(a) It would require considerably more fuel for take-off and landing, especially if the method for achieving vertical lift is by lifting fans or jet lift.

(b) The aircraft would occupy the area over the site for much longer, thus restricting the number of take-offs and landings per hour. It would take of the order of 30 - 40 seconds for the aircraft to climb to 1,000 ft., and a similar time for landing, plus further time to accelerate away from the site.

(c) The pilot would have a poor view of the landing area directly beneath him.

(d) Instrument approaches would be more difficult because guidance from the ILS is not wide enough to adequately warn the pilot that he is about to intercept the path. As a result he is likely to overshoot and hence would have to move backwards or initiate a high rate of descent if he is coming down at a steep angle. Distance measuring equipment will be required to tell the pilot how far he is from a point vertically above the site so that he can accurately carry out the transition from horizontal to vertical flight.

A more likely operation would be to approach and take-off at a shallow angle. An angle of 10°, giving a gradient of 1 in 6 should be more than adequate for obstacle clearance. The aircraft would fly down the ILS path, decelerating so as to arrive at the touch down point at low forward velocity. The pilot's view of the landing area would be much improved compared with that when descending vertically or at a steep angle. For poor weather approaches distance measuring equipment would enable the pilot to monitor the decelerating process. Approaching or taking-off at an angle of 10° will, however, place a greater premium on noise reduction.

The development of all weather automatic take-off, approach and landing systems for VTOL aircraft is one of the areas where considerable research is required because of the limitations imposed by the size of the VTOL port, its location in built up areas, obstacle clearance and noise abatement problems. The equipment will have to be used in clear weather for some time to enable its reliability to be determined before operations are started in conditions of poor visibility. A further development in this area is the need for accurate en route navigation systems which will enable aircraft to operate safely in congested air space.

Noise

Whatever method is used for achieving V/STOL, one of the most important considerations is the need for a low noise level. The current requirement appears to lie in the region of 95 PNdB at a distance of 500 feet and even this may be thought high for an aircraft taking-off and landing in a residential area. To get these figures in perspective, the noise of current short haul jet transports at 500 ft. is about 120 PNdB when taking-off, and 108 PNdB when at approach power. This suggests that a low noise level will have to be achieved even at the expense of degraded economics. Internal noise in the passenger cabin is also important from the point of view of competition with advanced surface transport systems. The effects of noise on the aircraft structure may be another problem area.

A quiet V/STOL aircraft is almost inevitably a machine with low thrust disc loading, typically a deflected slipstream or tilt rotor system or some form of helicopter. This is typically illustrated in Figure 18 from Reference 7.

Using current techniques it would seem that high disc loading fans and jet engines, with or without bypass, are ruled out. Although on a longer term basis, work being carried out by Rolls-Royce on advanced self-contained lift engines using bypass ratios of 8 - 12 indicates that it may be possible to achieve a considerable reduction in noise level. If the large diameter propeller or rotor is used then noise reduction may be achieved by:-

(a) Low disc loading.
(b) Low tip speed.
(c) Suppression of the compressor and exhaust noise of the engine.
(d) Suppression of gearbox and drive mechanical noise.

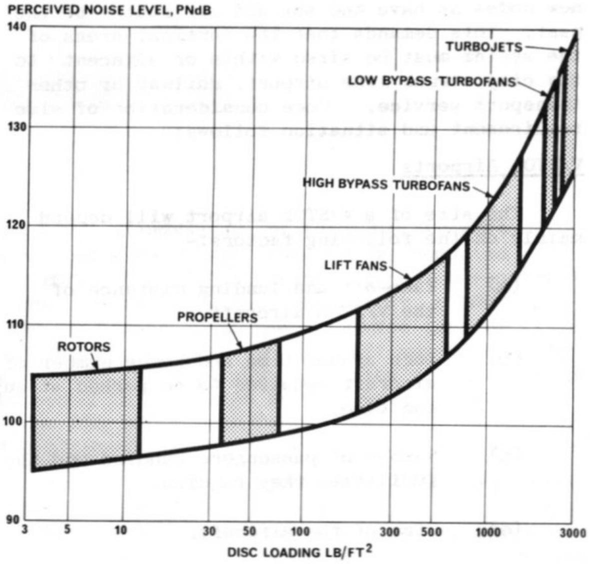


FIGURE 18 VARIATION OF OVERALL NOISE LEVEL WITH DISC LOADING FOR A MEDIUM-SIZED V.T.O.L. AIRCRAFT

Lowering the disc loading reduces propeller efflux noise, but beyond a certain point blade and vortex noise becomes dominant (as regards propeller noise) and the criteria advanced by Hargest (Reference 8) appears to suggest that propeller tip speed is the main parameter in this region, followed by blade lift coefficient and then blade area. Gearbox noise can also be a considerable contribution on low disc loading systems, the use of suitable gear tooth loadings and tooth frequencies may assist here. The use of choked inlets and ducts constructed of sound absorbent material will help to lower the noise from the engine compressor. Engine efflux noise will depend mainly on efflux velocity which will be fairly low on a turboshaft engine. Further noise suppression of the efflux can be achieved by fitting silencers of the type used on current jet transports.

The noise below the take-off and landing paths can be reduced by steepening the climbout and descent angles. This will require a high power/weight ratio combined with a reasonably high lift/drag ratio in the take-off configuration. For landing, a steep angle requires high drag, with the ability to reduce the drag in order to go round again in the case of a baulked landing, and an automatic guidance and control system designed for steeper angles than those currently used. The V/STOL sites should also be sited such that the take-off and landing paths are over non-residential areas or along railway lines and motorways.

Airport Considerations

General Requirements

An inter-city-community service transport system is essentially a link system tying together local movement within communities with long range transport terminals, or to facilitate movement between communities. The whole system, therefore, must be integrated into existing facilities or populated areas. The existence of the system is unlikely to generate new nodes as have the sea and air routes of the past. This demands that the terminal areas of the system must be sited within or adjacent to the city, trunk line airport, railway or other transport service. Some consideration of size requirement and situation follows:

V/STOL Airports

The size of a V/STOL airport will depend mainly on the following factors:-

(a) Take-off and landing distance of the V/STOL aircraft.

(b) Turn around time and hence number of aircraft required to be parked at any one time.

(c) Number of passengers handled and the facilities they require.

(d) Size of the aircraft.

(e) Car parking and surface transport facilities.

All but the first factor are inter-related because as the number of passengers per hour increases both the aircraft size and the number of aircraft to be parked for loading and unloading. tend to increase.

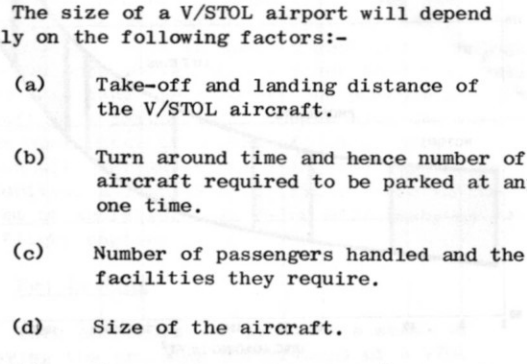


FIGURE 19 AIRPORT FOR HANDLING SMALL HELICOPTERS

Thus the smallest airport would be one for operating relatively small helicopters or other VTO vehicles one at a time. Figure 19 illustrates the probable size of such a site; it would occupy just over 2 acres.

As illustrated this would be an elevated site with room for car parking below. Such a site could handle up to about 4 aircraft an hour, i.e. 10 minutes for unloading and loading, refuelling, etc., and 5 minutes for landing and taking-off and clearing the aircuit for the next aircraft.

Assuming 25 flights in and 25 flights out per day, using a 30 seater at 55% load factor, the total passenger movement per year would be about 300,000. A site of this size could handle larger VTO aircraft seating up to about 80 passengers. Although the use of larger aircraft enables the passenger movements to be increased, greater frequency and a more complex route structure would be required if the system is to compete with other forms of transport.

If the maximum number of aircraft handled per hour is increased to 10, i.e. 20 movements per hour, more aircraft parking space would be required, along with taxi ways between parking areas and the take-off and landing pad. It is assumed that a separate take-off and landing pad will be required because:-

(a) The downwash from the large rotors or fans could damage parked aircraft, and hinder the work of the maintenance crew and the loading and unloading of passengers. The downwash problem increases as the aircraft A.U.W. and efflux velocity increase. The pad could consist of a grille with ducts below which would duct the downwash away from the rest of the site.

(b) The automatic landing system would guide the aircraft down on to only one part of the site.

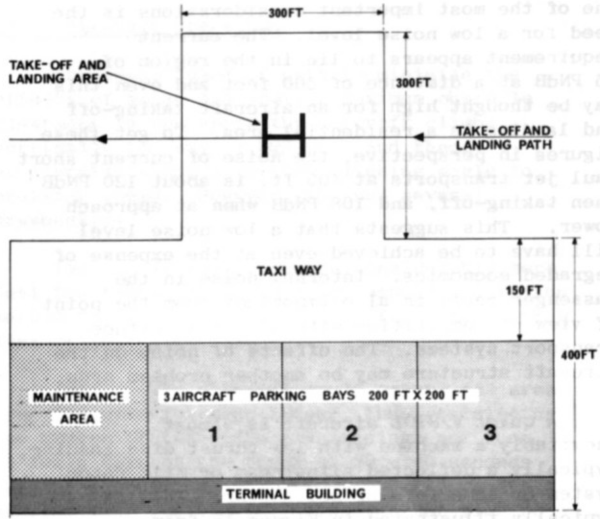


FIGURE 20 AIRPORT FOR HANDLING LARGER V.T.O.L. AIRCRAFT

Figure 20 illustrates the probable size of a site to meet the above requirements. It occupies about 9½ acres.

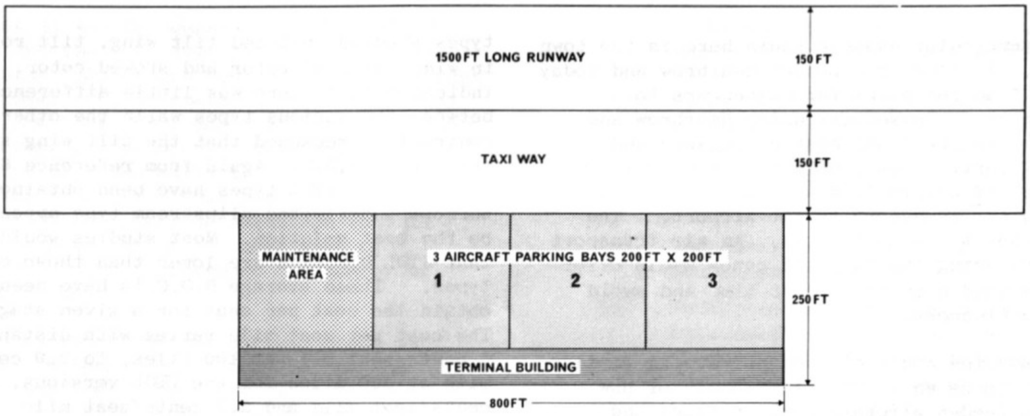


FIGURE 21 AIRPORT FOR HANDLING S.T.O.L. AIRCRAFT

Assuming an aircraft of 60 seats capacity, 75 flights in and 75 flights out per day, and 55% load factor, the total passenger movement per year would be about 1.8 million. In comparison London (Heathrow) Airport handled about 12.6 million passengers in 1967, and London's Waterloo railway terminal handles about 80 million passengers per year.

A site for operating STOL aircraft would be similar to the site for VTOL aircraft but with the landing pad replaced by a runway 1,500 ft. long. Figure 21 illustrates such a site.

This site would occupy about 15 acres, i.e. about 50% more than a site for VTOL aircraft. Thus the extra expense of building the STOL site would have to be off-set by the lower operating costs of the STOL aircraft compared with a VTOL one. It is assumed that the take-off and landing areas for both the VTOL and the STOL aircraft would be built above a road or rail track and hence provide clear approach and take-off paths. This also means that the only new land required would be that for the terminal building and aircraft parking area. Again, being an elevated site there would be plenty of room below for car parking, shops, surface systems, etc. As an example of comparative size Figure 22 shows the STOL airport referred to above superimposed on a plan of Victoria railway terminus station, although it is not suggested here that this is necessarily a potential site.

A STOL site for only a small number of movements per hour would be very much bigger than the one proposed for VTOL aircraft (Figure 19) but as the number of movements is increased the area required for parking aircraft and the terminal building becomes a bigger proportion of the total.

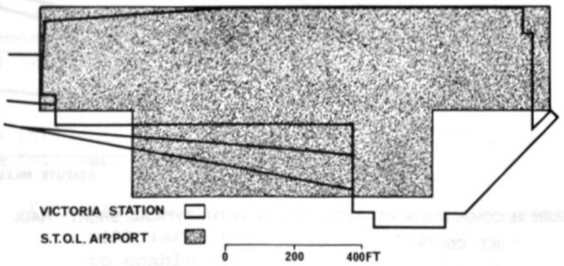


FIGURE 22 COMPARISON OF S.T.O.L. AIRPORT WITH VICTORIA RAILWAY STATION LONDON

Hence the disadvantage of the STOL aircraft requiring a relatively long runway tends to diminish. The VTOL aircraft might also require a longer landing area than the 300 ft. x 300 ft. shown in Figure 20 if the automatic landing system required that the aircraft approach angle be only 6°, with an approach speed of 45 knots, as suggested in Reference 9. This would further reduce the difference between the cost of VTOL and STOL sites.

Space for STOL airports of the size referred to here can be found close to and even in built-up areas and cities. Figure 23 shows alternative locations in a typical urban area. All are within one mile of the centre of business and of the existing transport facilities, train and road. The example shown in the figure is a town of 80,000 people. One of the locations is shown as a roof over the existing goods yard and sidings and in this case would therefore allow easy transfer of passengers and freight and improve the utilization of valuable land.

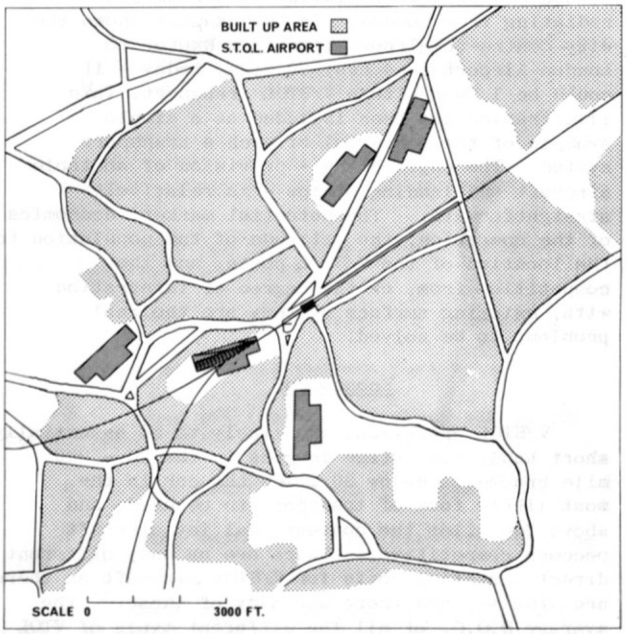


FIGURE 23 MAP OF A TYPICAL ENGLISH PROVINCIAL TOWN SHOWING GEOGRAPHICALLY POSSIBLE SITES FOR A S.T.O.L. AIRPORT NEAR ITS CENTRE

The particular example shown here is the town of Woking, 15 miles from London Heathrow and today a railway transfer point for passengers to London Airport. Passengers using Heathrow and originating in the South West of England and using this service, currently travel by rail from their point of origin to Woking where they change to a coach for transport to the airport. The coach journey takes 45 minutes. An air transport service replacing the rail and coach would offer greatly reduced home-to-airport time and avoid traffic bottlenecks.

The service would pick up at several similar provincial towns en route. An example of how the V/STOL feeder aircraft could replace and improve on an existing system follows.

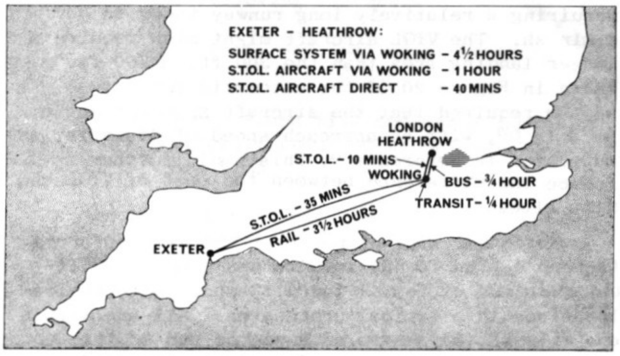


FIGURE 24 COMPARISON OF TIMES TAKEN BY S.T.O.L. AIRCRAFT AND PRESENT DAY SURFACE SYSTEM FOR A TYPICAL 150 MILE JOURNEY

Figure 24 shows this possible intercity - feeder service. Several other rail links serve London Heathrow in a similar manner on routes radiating from London. In the example shown the city-centre-to-airport time from Exeter to London Airport is 4 hrs. 30 mins. today - it could be 1 hour with a V/STOL transport. This illustration has been included as a simple example of the potential of such a transport system. The engineering - provision of suitable aircraft and landing strips - is relatively straightforward. The potential market, economics of the operation, the attitude of the population to the location of the V/STOL ports, and the competition from, or the degree of integration with, existing surface systems are the real problems to be solved.

Economics

V/STOL operations are likely to be essentially short haul, i.e. stage lengths in the 20 - 300 mile bracket. Below 20 miles the car is the most likely form of transport to be used, and above 300 miles the conventional jet aircraft becomes competitive. There are as many different direct operating costs for V/STOL aircraft as there are studies, and there are many of these. The average D.O.C. of all the different types of VTOL systems studied by Boeing, Lockheed and L.T.V., for the recent NASA Short Haul Transport Study, Reference 6, has been obtained. The different types studied included tilt wing, tilt rotor, fan in wing, stopped rotor and stowed rotor. Lockheed indicated that there was little difference in D.O.C. between the various types while the other two contractors reckoned that the tilt wing system had the lowest D.O.C. Again from reference 6 the D.O.C.'s for STOL types have been obtained, the turboprop deflected slipstream type appearing to be the best solution. Most studies would indicate that STOL D.O.C.'s are lower than those of VTOL types. These average D.O.C.'s have been used to obtain the cost per seat for a given stage length. The cost per seat mile varies with distance from 5 cents/seat mile at 100 miles, to 2.9 cents/seat mile at 500 miles for the VTOL versions, and 3.5 cents/seat mile and 2.1 cents/seat mile respectively for the STOL versions. This cost per seat has been doubled to allow for a 50% load factor which one has to work to in order to provide a reasonable service.

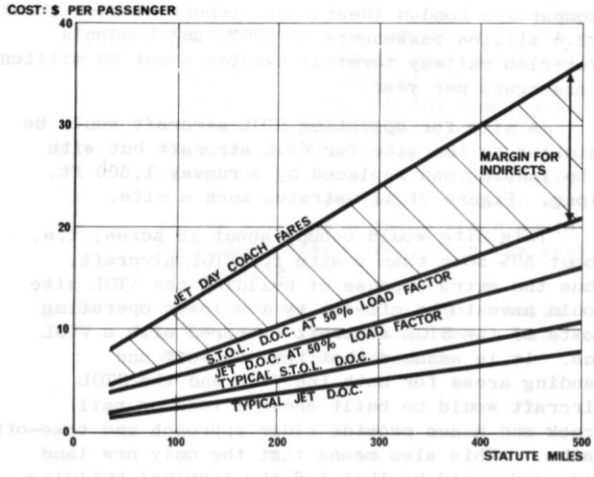


FIGURE 25 COMPARISON OF S.T.O.L. COSTS WITH TYPICAL SHORT-HAUL JET COSTS

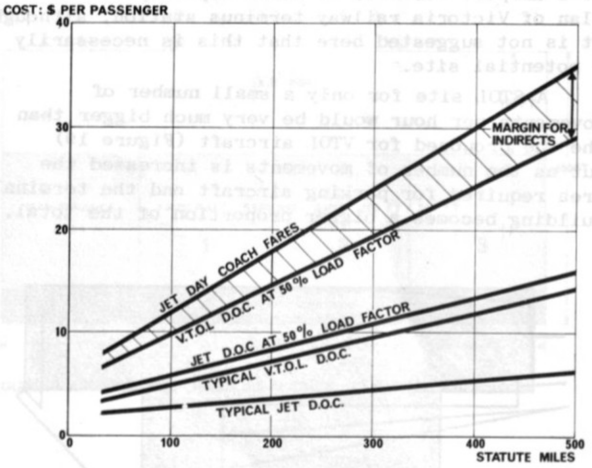


FIGURE 26 COMPARISON OF V.T.O.L. COSTS WITH TYPICAL SHORT-HAUL JET COSTS

Figures 25 and 26 compare the STOL and VTOL costs with average U.S. domestic jet fares. Also shown in these figures are conventional jet direct operating costs. These costs have been obtained from the C.A.B. jet costs and statistics for the BAC One-Eleven and the DC-9. These jet aircraft average about 80 seats while in the NASA studies each type had 60 seats. This tends to give the conventional jet aircraft an advantage in this comparison because one of the best ways of reducing D.O.C.'s is to increase the number of seats in an aircraft.

As can be seen from the curves, there is little margin between the VTOL D.O.C. at 50% load factor and the current jet fares to allow for indirect costs, especially at short stage lengths. Thus either some way will have to be found to reduce the VTOL aircraft D.O.C.'s, or higher fares would have to be accepted. For the STOL aircraft there is a higher margin available for indirect costs and hence a smaller increase in fare would be required to cover the extra operating costs. At the moment the very short haul services tend to be subsidised by the longer haul traffic on the basis that they act as feeders to the more profitable longer haul services, or they are subsidised by government funds on the basis that they are a service to the community, like some of the U.S. local service carriers.

Thus it seems that the VTOL, and to a lesser extent STOL, short haul fares may need to be higher if this type of service is to be profitable. This is reasonable if a better service is being provided, e.g. a saving in time is presumably worth something to the customer, and although the rate per mile might be high the total is relatively modest due to the short distance involved.

As mentioned above, the margin for indirect costs is low and on moderate stage lengths these indirect costs are reckoned to be about equal to the direct costs. Since the indirect costs tend to be a fixed amount per passenger trip, the indirect costs as a proportion of the total costs rise with decreasing stage length. Hence on very short haul routes just as much attention needs to be paid to reducing the indirect costs as to reducing the direct costs. Examples of indirect costs are:-

Reservation costs.
Boarding supervision.
Baggage handling.
Landing fees.
Cabin servicing.
Fuelling etc.
Station costs.

Also the short stage lengths mean that block speeds are reduced, annual utilization is reduced, and maintenance costs are high.

A lot of these items the aircraft designer can influence, and thus help to reduce the costs. The following suggestions are made:-

(a) Easy access to the aircraft is required with large entrances and wide aisles to enable the passengers to embark quickly and thus reduce turn around times. This will reduce the number of aircraft to be parked at any one time and hence reduce the size of the airport.

(b) Provision for the passenger to carry on fairly large items of baggage and be able to stow them near his seat, and hence reduce the amount of baggage handling by airline staff.

(c) The carriage of air stairs so that ground equipment is not required.

(d) Sufficient capacity for fuel and other consumable fluids to enable many short stages to be flown without refuelling. This will again reduce turn around time.

(e) Sufficient internal power from an A.P.U. for ground air conditioning, engine starting, etc., so that no ground equipment is required.

(f) The carriage of an accurate en route navigation system and the ability to operate in all weathers to increase block speed and utilisation.

(g) The design of the structure and systems to reduce maintenance requirements and to have a long time between overhauls, and to take into account the very large number of flights per year.

(h) The reduction in take-off and landing distances and turn around times which will reduce the size of the airport and hence reduce the landing fees.

(i) Aircraft easy to manoeuvre on the ground with small turning circles to reduce size of taxi-ways and parking areas.

(j) Large C.G. range to make less critical loading.

Market Prospects

Before an assessment of the likely market for V/STOL aircraft can be made, the following questions need to be considered:-

1. What are the current passenger flows between city pairs by the various modes of transport and where are their actual origins and destinations?

2. What are the costs associated with travel between city pairs?

3. What are the reasons for travelling?

4. What are the current fare levels?

5. What are the average block speeds for the different modes of transport?

6. What traffic growth is forecast?

7. What value will the traveller place on time saving?

8. What performance and cost levels will V/STOL aircraft have and what likely improvements will subsequent development give?

9. How will other modes of transport

improve in the timescale?

10. Will local authorities and the general public accept the operation of V/STOL from city centres and urban areas?

11. What V/STOL airport sites will be available and what will be their position relative to the city centre and other modes of transport?

12. Who will operate V/STOL aircraft and how will operations be started?

It would seem obvious that if V/STOL aircraft could be operated between city centres at fares a little higher than the current airline fares, then a considerable number of passengers who would normally travel by air on aircraft such as the BAC One-Eleven, DC-9, 737, Caravelle, Vanguard, etc., would transfer to the V/STOL aircraft for distances less than about 400-500 miles because of the time saving and convenience. Thus on this basis alone there could be a market for several hundred aircraft, plus those required to meet the demand from passengers who have diverted from surface modes of transport because of the time saving, plus further demand due to future traffic growth. Hence, it would seem that the market for V/STOL aircraft will depend mainly on two things:-

(a) Can V/STOL aircraft be built which will operate profitably at fare levels a little above those for current aircraft? Studies carried out by various aircraft companies would probably answer this question with a tentative yes. The actual number required would then depend on the answers to questions one to nine.

(b) Will suitable sites be available and will they be acceptable to the general public, (questions ten and eleven). The answer to this question will depend on what noise levels will be emitted by the aircraft, what level of safety can be demonstrated, and what land is available for airports. These are much more difficult problems and the magnitude of them is illustrated by the fact that at the moment a large proportion of local authorities are against the development of V/STOL sites in their cities. Thus considerable work will be required to develop aircraft which will have much lower noise levels than current aircraft (both conventional and V/STOL), and to convince the authorities that these aircraft have a level of safety acceptable to local inhabitants. On these last two points will depend the future market for inter-city V/STOL aircraft.

A further market for V/STOL aircraft, especially STOL types, would be for flying between small airfields whose runways are too short for current jet aircraft. This might provide better facilities for travelling to smaller towns or holiday resorts which do not have large airfields near by. Also such aircraft could be used in less developed parts of the world where large runways are expensive to construct and the frequency of service does not justify expensive facilities. These last uses may be the answer to the problems raised by question 12. A STOL aircraft could be developed initially and operated from short airstrips closer to the city centres than the large airports. When the service had developed, true city centre sites could then be built.

Summary and Conclusions

From all work done and from transport studies both academic and of a practical exploratory nature, there appears to be a clear need for an intercity, feeder or commuter type transport system. It would seem that this would operate over the distance of from 20 to 50 miles at the one end, to 200-300 miles at the other. There will be strong competition for this business from an assortment of surface systems, particularly at the short range end and in densely populated areas. At the long range end it would seem that a V/STOL service could relieve the pressure at the shorter and less economic range of current short haul operations, and help considerably toward reducing runway length requirements and the difficulty in finding available land for this purpose in highly populated and industrialised countries.

STOL aircraft are very little removed from conventional types, being a development, basically, in improving the low speed lift capability of the machine, and there are many examples flying and operating experimental services of this type. On the other hand although over the last 20 years there have been many different experimental VTO aircraft, no one solution seems to be dominant; the only commercial operations have been with the use of the helicopter. As we know it today, the helicopter does not offer a commercially viable transport system, although developments of rotary wing aircraft might well do. The VTO vehicle, therefore, is a further step removed from conventional aircraft.

Operating in the vicinity of the airport, STOL aircraft can follow similar procedures to that adopted by conventional aircraft, although new certification rules may well have to be employed. VTOL aircraft whilst having an "ideal" ability requiring no longitudinal climb out or approach phase, possibly may not be able to use this capability when automatic landing procedures are used. Its operations could be restricted, either to visual, or by adopting a glide path technique. Under these conditions and when multiple operations are considered, passenger handling and car parking space have been allowed, the VTOL airport may not be significantly smaller than STOL airports. In theory sufficient space exists for STOL airports near or within most urban areas; experimental aircraft of the Breguet 941 (McDonnell 188) and D.H. Canada Buffalo type have demonstrated this capability.

From the many economic studies made it is clear that at the present state of knowledge, STOL aircraft have a strong advantage and approach current short haul figures. It is not clear, however, whether there is a public need or desire for an intercity community service system. But history shows that civilisation does not accept new developments readily but when they are made available it wonders how it ever managed without them.

Conclusions which can be drawn are:-

1. STOL operational aircraft are available

today but that considerable effort on the part of operators is needed to promote a viable commercial system.

2. Relatively more research and development is needed on the VTOL vehicle before it becomes commercially attractive.

3. Safety and airworthiness requirements have yet to be established. These in turn will depend on some experimental operational experience.

4. Noise or other community nuisance aspects must be understood, and the measures to combat these found to be achievable.

5. Considerable research is required into all weather operations and navigational aids. These have a substantial bearing on airport size and location. Also A.T.C. needs to be developed to enable V/STOL aircraft to operate into conventional airports without increasing the congestion

6. A clear indication is that the initial approach into a new intercity, feeder and community service transport system should be through STOL.

7. Considerable research is required into the social need and travel requirements of people, and that this needs to take a large sample world wide owing to the different local conditions.

8. Considerable research is needed in the town and country planning aspects toward siting of airports.

9. A detailed appraisal of competing forms of transport should be made, and possible integration of systems studied.

10. All-embracing (door to door) economic studies should be made toward the assessment of commercial fare levels.

STOL commercial operations appear, therefore, to be just around the corner. VTOL commercial operations may be a decade or so away, but, as and when a STOL inter-city transport system develops, the improvement of STOL performance toward VTOL may well become attractive and perhaps even necessary.

The authors wish to state that this paper represents their own views and does not necessarily reflect British Aircraft Corporation policy.

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