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Intercity VTOL Aircraft

A Hawker Siddeley Review

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It is an observation that has been made several times before that the process of moving people and goods nationally and internationally is one of the largest single activities of human society. It is an activity that will go on for many years to come and with increasing intensity.

Across the middle of this century we have seen the business of international passenger traffic being transferred from the sea to the air. From the '60s onwards the increasing volume of air traffic began to be faced with a serious terminal problem. Congestion at the airport terminals both on the ground and in the air forced one city after another to provide a second airport and in some cases a third. This growth situation led the authorities concerned to look for alternative solutions to the problem. In the North East Corridor of the United States the possibility of operating a complimentary air service involving aircraft with STOL qualities in parallel with the CTOL system was considered. Several studies and tests were carried out. In particular Eastern Airlines put out a specification for one such vehicle.

In the U.K. and in Germany studies and development work had been going on in the early '60s for VTOL military and civil transport. In fact there was Dornier/De Havilland collaboration of considerable effort following the NATO (NBMR 4) specification. This included the Do 31 development. In the U.K. the Ministry and Industry together with their specialised committees had been examining both the STOL solution and the V/STOL solution to the intercity air transport problem.

In general terms, about 1966-68, majority agreement seemed to be reached that the VTOL concept was the most fruitful concept to develop. In early 1969 both Germany and the U.K. issued specifications for VTOL intercity aircraft. The specifications for both the Eastern Airlines, and the German and British aircraft are shown on Figure 1.

Quite a number of solutions were proposed for the Eastern Airlines Spec. but for a number of reasons, including the energy crisis and the world recession in trade, these proposals were not pressed to fruition.

The response to both the German and the U.K. ministerial requirements was extremely effective. The German 'winner' of the 'contest' judged by the Thallau Committee was the Dornier Company with VFW and extremely close second. Both these companies put forward a fan lift concept. In this country, Hawker Siddeley who had examined thoroughly both the NGTE circulation controlled rotor and the fan lift concept came out firmly in favour of the fan lift and put forward a configuration designated the HS 141. The HS 141 and CCR aircraft are shown on figures 2 and 3 respectively. Figures 4 and 5 give leading characteristics and payload-range chart of the HS 141.

The action that followed the examination of the British submissions to the Ministry VTOL Spec. was taken by the TARC. This Committee ruled that they required a study on the STOL solution to the intercity problem in similar depth to that which had been carried out on the VTOL exercise. This was undertaken by the appropriate departments of the Ministry and by Industry and in fact is still going on at low priority. The reason for this lowering of pressure on attempting to obtain a solution to the terminal congestion problem could be found in the energy crisis that had affected the whole world situation. There has been rescheduling of routes and some rationalisation in dealing with the travelling public. Linked to this has been the introduction of the wide bodied aircraft. The travelling public has lately been divided into two main classes. The passengers who can book well ahead for their requirements (e.g. inclusive tour) and those who require business travel at short notice. There has been a growing tendency with the former class to be provided with transport from their local airports as well as from London. However, the latter class requires reasonable frequency of service. This in fact is essential and will lead, in due course, to the same congestion problems as we have just gone through.

We shall now look at the general trend in world travel in the broadest terms. Figure 6 shows the number of passenger kilometers per year up to 1974 and the predicted figures up to 1990. You will note that it is predicted that the energy crisis will not be noticeable in due course. With this growth and if we proceed with the use of CTOL aircraft only, sooner or later the problems of congestion and noise, pollution etc. will re-occur and further terminals will necessary.

We should therefore re-examine the characteristics of STOL and V/STOL aircraft. In doing this we can make observations against our present experience.

A further factor which lessened the active design work on the V/STOL concept was the bankruptcy of Rolls Royce in 1971. This led to the shelving of the fan lift engine, the RB202. This engine had been an essential component of both the proposed German and British VTOL airliners. At that time the prospects for the RB202 were extremely good. Agreement of the broad principles of design thrust/weight ratio, fuel consumption and noise characteristics had been agreed between Rolls Royce, the NGTE and the Ministry and in fact limited contracts were being placed.

Now that Rolls Royce 1971 have got over their difficulties it would seem very appropriate indeed that research and development on this class of engine should be re-opened.

Before examining STOL and VTOL, I wish to define the characteristics of the various categories of civil aircraft. Figure 7 shows the various regimes. CTOL stretches from 4,000 feet upwards to 6,000 feet on this figure. In fact the balanced field length for the 707 and 747 classes of aircraft is just under 11,000 feet.

RTOL is shown at 3/4,000 feet and requires improved flap arrangements to design a competitive aircraft. STOL is shown between 1,500 and 3,000 feet. If aerodynamic means alone are used to provide this performance it implies a very elaborate flap system together with low wing loading. As far as civil transport is concerned it may be said to be impossible to go below 1,500 feet.

If we go to powered lift and use indirect means such as boundary layer control, jet flap etc. we see that we rapidly approach a dangerous area and finally reach an impossible region. If we use powered lift directly we get a straight forward change over from STOL to VTOL.

Returning to the examination of the characteristics of STOL aircraft, the following figures are important. Figure 8 shows the approach speed against maximum approach angle for an aircraft. It is common practice to limit vertical velocity to something under 1,000 feet per minute. You will note this tends to preclude greater angles of descent than $7\frac{1}{2}/8^{\circ}$. Figure 9 shows approach speed against runway length.

The next figure, 10, shows the approach speed associated with the wing loading for different usable lift co-efficients. Figure 11 shows passenger comfort associated with speed and altitude and indicates the undesirability of low wing loadings. The next figure, 12, shows a table which is derived from these curves and is included for clarity reasons. The final figure, 13, on STOL characteristics shows yaw angles against field length and this indicates that it may be necessary to have two runways for STOL terminals. It should be said here that STOL aircraft are extremely sensitive to gust conditions in the terminal phase. A STOL aircraft designed to meet an up gust of 30 feet per second could be somewhat different than one designed to meet gusts of 40 feet per second. A further complication of STOL aircraft is that provision for power plant or sub-system failure may lead to considerable complications in design. It is therefore untenable to hold that STOL aircraft provide a simpler solution than VTOL aircraft.

The next series of figures bring out the value of the VTOL concept. Figure 14 shows the acreage required for a CTOL, STOL and VTOL airport. If one considered that apart from the claims that have been put forward with respect to this it must be admitted also that the total energy required to supply a VTOL airport is considerably less than that for a CTOL airport. The next figure, 15, shows the area of noise and pollution round the respective airports. Figure 16 gives an indication of the cost of the respective terminals in £s sterling about 1970. The next figure, 17, shows how VTOL aircraft could be operated in parallel with CTOL aircraft by resorting to traffic segregation. Figure 18 shows the weather minima and approach aids. It will be noted that the VTOL aircraft requires less complex systems than the CTOL or STOL.

The despatch reliability of having a number of engines as exist in the HS 141 class of VTOL aircraft has often been questioned. As this argument is somewhat involved I have put it as an appendix at the end of the paper.

Figure 19 shows the relative first costs of the respective aircraft. Figure 20 shows relative direct operating costs for a

300 statutory mile stage and figure 21 shows the relative total journey cost when the whole system is taken into account. Figure 22 shows the total journey time for the three air transport systems.

It has been generally assumed that intercity VTOL aircraft will themselves consume more fuel than the corresponding CTOL aircraft. In his recent Stringfellow lecture, J. T. Stamper reference 1 examined this point on the basis that the effectiveness of a transport system is judged on the total journey time. Figure 23, (fig. 22 in reference), has been taken directly from this lecture. It shows a series of VTOL aircraft designed for different cruising speeds and compared with a 600 mph CTOL aircraft as datum. As expected the 600 mph VTOL has a higher fuel consumption than the corresponding 600 mph CTOL aircraft. This is roughly 18% more for both the 200 and 500 mile stage distances. However, even at the same cruising speed the VTOL aircraft will have a somewhat shorter flight time than the CTOL aircraft because of its steeper ascent and descent paths in the terminal area. This is why the 600 mph VTOL point shows minus 6 minutes on the journey axis time. It will also be observed that the 500 mph VTOL is as effective in terms of flight time as the 600 mph CTOL and has roughly the same fuel consumption. On the same argument a 400 mph VTOL aircraft would allow a reduction in fuel consumption of 10% compared with the 600 mph CTOL aircraft. However, VTOL can potentially reduce journey time by as much as one hour thus we see that a relatively small part of the VTOL time saving advantage can be traded off to actually save fuel compared with CTOL.

This point was fully gone into in this lecture but it is relevant in my paper today.

Figures 24 and 25 show that the unique characteristics of the VTOL aircraft can be used to provide an aerial tube type of transport system. The technology is available to do this. These figures are self-explanatory.

Although in the broadest terms the many problems that were facing the extension of the use of CTOL aircraft into the future in the late 1960s have been considerably eased for the present. There are still many serious and pressing problems that are with us. If for example we take the problem facing Japan with the provision of its international airport at Narita, it is still far from satisfactory. It is probably among the worst invasions into the environment that has occurred in the peaceful world. There has been violence and death. There has been opposition to the laying of fuel pipes. A steel tower obstructs the flight path to the main runway and the airport is still not in use. Anyone reading its history must surely agree that it is wise to press forward the immediate development of VTOL.

Other problems are the provision of terminals for low density communities who cannot afford conventional airports. Sumburgh in the Shetlands which has now been provided, at the relatively cheap cost of £6/7,000,000 would have been eliminated had longer range VTOL technology been developed. In other cases we are denied the opportunity of providing satisfactory air transport systems in holiday areas because the mere provision of conventional terminals would destroy the amenities. Figure 26 shows such a terminal on Beef Island in the complex of the Caribbean air transport system. No comment on this is required.

Finally I would like to answer a question as to how long it would take to set up a V/STOL transport system. For this I go to a figure taken from reference 3 and this indicates that technically the time would be 10/12 years from ITP.

The great holding factor facing the development of intercity VTOL transport is the fact that it is not being looked at as a whole by any one responsible authority. Its essential components are the responsibility of unrelated Ministerial bodies.

ACKNOWLEDGEMENT

Although this paper reviews some portion of Hawker Siddeley material on VTOL aircraft, the views expressed are personal. They do not necessarily represent those of my Company. I am grateful for permission to publish this paper.

APPENDIX

Dispatch Reliability - Dependence on Engine Unserviceability

The total dispatch reliability of current short haul turbo-fan aircraft lies in the region of 97 - 98% in 'mature' operation, depending upon the particular aircraft and engine characteristics and to a certain extent on the airline. The Design Target for the new generation of aircraft, including the tri-jets is 99%. Thus the total delays of 1% include the contribution due to the powerplants and typically this may amount to about one fifth of the total.

The discussion in this paper will be confined to dealing with the effect of the number of engines on dispatch reliability.

If we consider a group of N engines, each of which has a probability p of unserviceability per take off, then the probability of a delay due to an engine snag is Np. Thus by implication, for the new generation of aircraft, the engine contribution of one fifth of a per cent implies a value of $p = 0.001$ or less for a twin and even lower for a tri-jet, whereas current experience for mature operation suggests that p may lie in the band of 0.001 to 0.003.

Taking typically $p = 0.002$, then for current conventional aircraft the effect of the number of engines installed on the dispatch reliability numbers affected by engine unserviceability is indicated in the upper table of Figure 1, Appendix.

Number of Propulsion Engines	2	3	4
Probability of delayed take-off due to one engine snag per 100 departures (i.e. %)	0.4	0.6	0.8

Now when we come to V/STOL aircraft with multiple lift engines, with numbers ranging between say 4 and 20, the probability analysis becomes rather complex. It is probably not in place in this paper to give the full algebraic solutions but the results of this analysis produce some interesting conclusions.

In line with the Min. Tech. requirement the V/STOL aircraft is designed for maximum payload and maximum range in ISA + 20°C at sea level, having the ability to cope adequately with a double lift engine failure. If the HS 141 with two propulsion engines and 16 lift engines is taken as an example, a first glance at the figures would suggest that the aircraft would have a poor dispatchability indeed. However, the following argument is put forward.

It may be assumed that on the vast majority of occasions, the flight plan may allow the aircraft to take-off with one or perhaps even two of the lift engines shut down because of unserviceability. This then alters the probability figures for delayed take-off as shown in the lower table.

In the case of the HS 141 with two groups of dissimilar engines performing different functions, the total probability of delayed take-off is the sum of the probabilities for either of the two groups of engines reaching the delay conditions.

Two sets of figures are presented in the table - the upper set (a) using p = 0.002 for all engines and the lower set, (b) using p = 0.001 for the lift engines. The values used for p of course are open to debate at this stage. Rolls Royce have quoted, in their submission to Eastern Airlines on V/STOL, a value of 0.1 per 100 departures (i.e. p = 0.001) for all engines. On a relative basis it is expected that the value for lift engines should be lower than for propulsion engines since they are considerably simpler and have less in the way of systems. It would, therefore, seem justifiable to show the effect of a lower rate on the lift engines.

Number of Lift Engines needed (out of 16)	16	15	14
Probability of delayed T.O. due to engine snags per 100 departures (i.e. %)			
(a) p = 0.002 for all engines	3.6	0.45	0.4
(b) p = .002 for propulsion and .001 for lift engines	2.0	0.41	0.4

This table may suggest that the dispatch reliability due to engine snags alone for the HS 141 looks bad in comparison with conventional aircraft if all the lift engines have to be functioning. However, if any one lift engine may be permitted to have a snag, thereby continuing the operation, then the VTOL aircraft is comparable with a twin jet conventional aircraft and better than the three or four engine jets.

The important fact is that if one lift engine snag is an allowable deficiency, the delay situation becomes dominated by the propulsion engines, and the effect of allowing a further deficiency (on a second lift engine) does not significantly alter the overall dispatch reliability.

Thus, this analysis indicates that the multi-engined fan lift V/STOL aircraft can be designed to have a dispatchability equal to, if not better than, contemporary conventional aircraft.

Because of the nature of aerodynamic STOL aircraft the loss of one engine in a twin engined configuration could be too heavy a penalty to design for. Aerodynamic STOL aircraft will tend to be 4-engined and the dispatch reliability will be consistent with that.

Dispatch Reliability

Number of propulsion engines	2	3	4
Probability of delayed take-off due to one engine snag per 100 departures (i.e. %)	0·4	0·6	0·8

Number of lift engines needed (out of 16)	16	15	14
Probability of delayed take-off due to engine snags per 100 departures (i.e. %)			
(a) p=0·002 for all engines	3·6	0·45	0·4
(b) p=0·002 for propulsion and 0·001 for lift engines	2·0	0·41	0·4

Fig. 1 Appendix

Outline requirements

	Field Length	Capacity	Range	Noise
MinTech	VTOL	100 seats	450sm	85·90PNdB in com'nty
Germany	VTOL	100seats	500sm	95PNdB at 500ft
Eastern Airlines	STOL 1500ft	150seats	575sm	95PNdB at 500ft

Fig.1

Fig.2

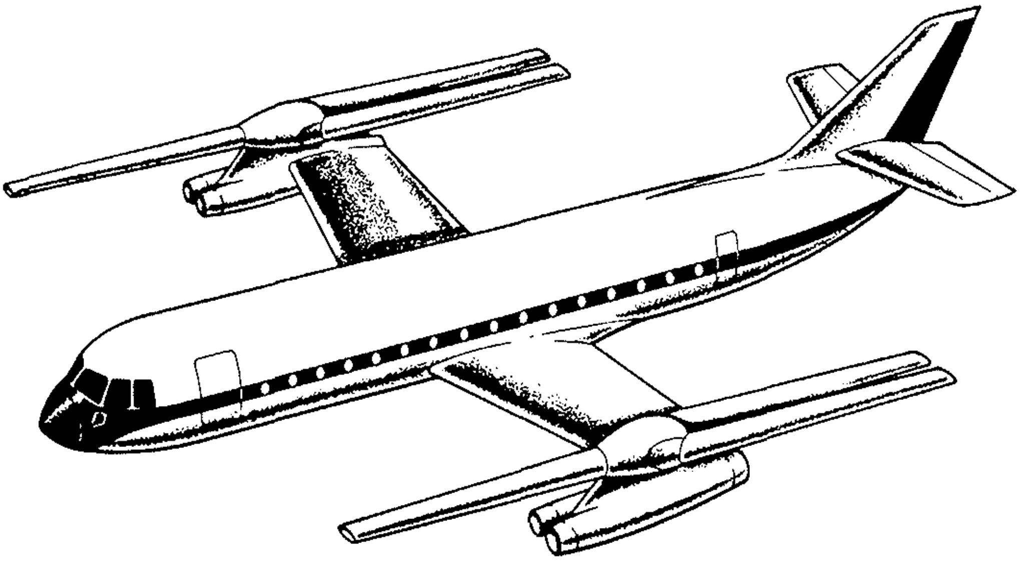


Fig.3

N.G.T.E. ROTOR

V/STOL

HS141 leading particulars

OVERALL DIMENSIONS:

Wing span	75 ft. 0 in.
Overall length	120 ft. 2 in.
Overall height	29 ft. 10 in.

DESIGN SPEEDS:

V_c	375 kt. EAS
M_c	0·85
V_D	435 kt. EAS
M_D	0·92

POWERPLANT:

Propulsion engines

Type	RB.220

Lift engines

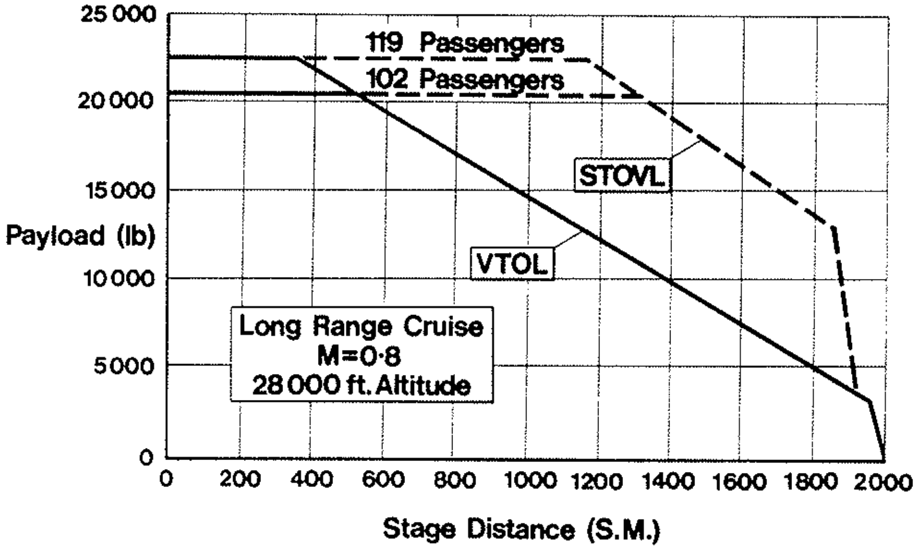
Type	RB.202-25

DESIGN WEIGHTS:

Design take-off weight	134 200 lb.
Max. VTO weight	124 200 lb.
Max. VTO ramp weight	124 500 lb.
Design landing weight	118 000 lb.
Max. zero fuel weight	110 300 lb.
Fuel capacity	33 500 lb.

Fig. 4

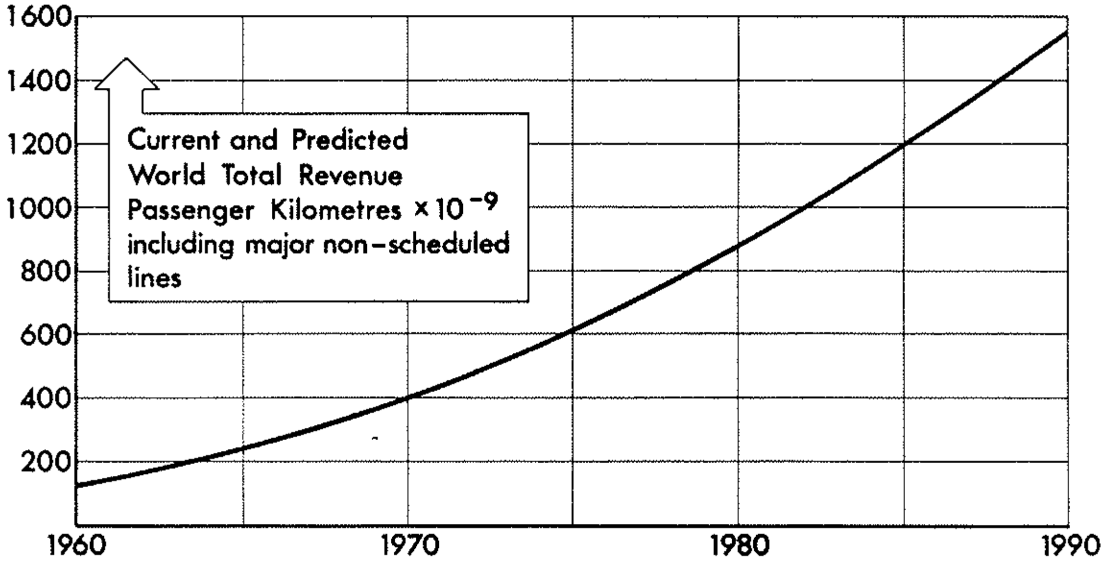
HS 141 Payload-range long range cruise



Long Range Cruise
M=0·8
28 000 ft. Altitude

Fig. 5

Passenger Kilometre ~ Time



Current and Predicted World Total Revenue Passenger Kilometres × 10^{-9} including major non-scheduled lines

Fig. 6

The Take-off and Landing Regimes

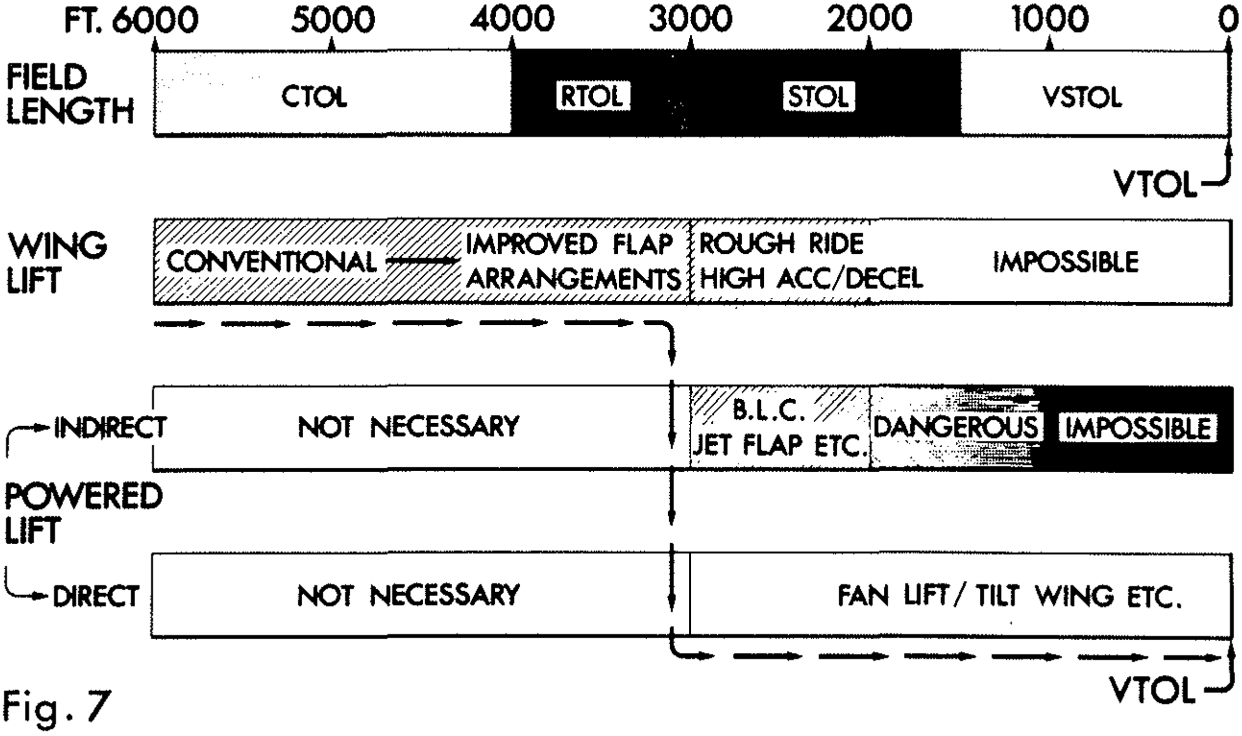


Fig. 7

Approach Speed and Maximum Approach Angle

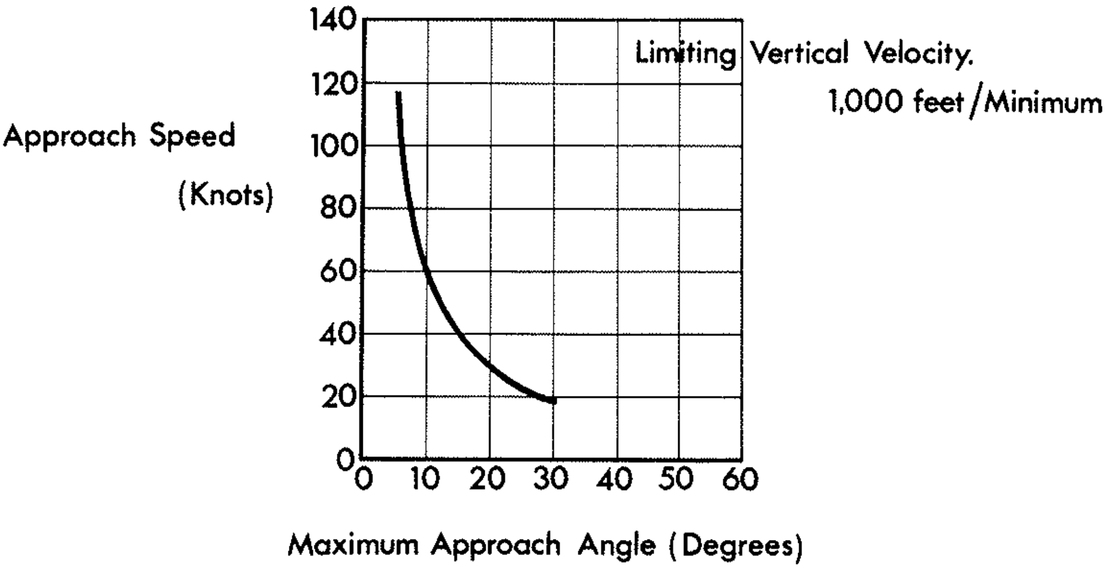


Fig. 8

Relationship Between Approach Speed and Runway Length (Simplified)

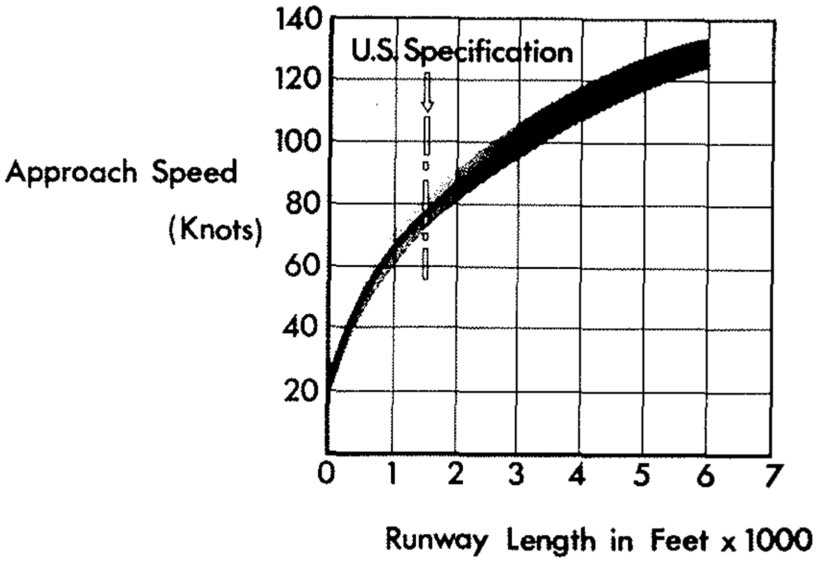


Fig. 9

W/S vs approach speed (Kts.)

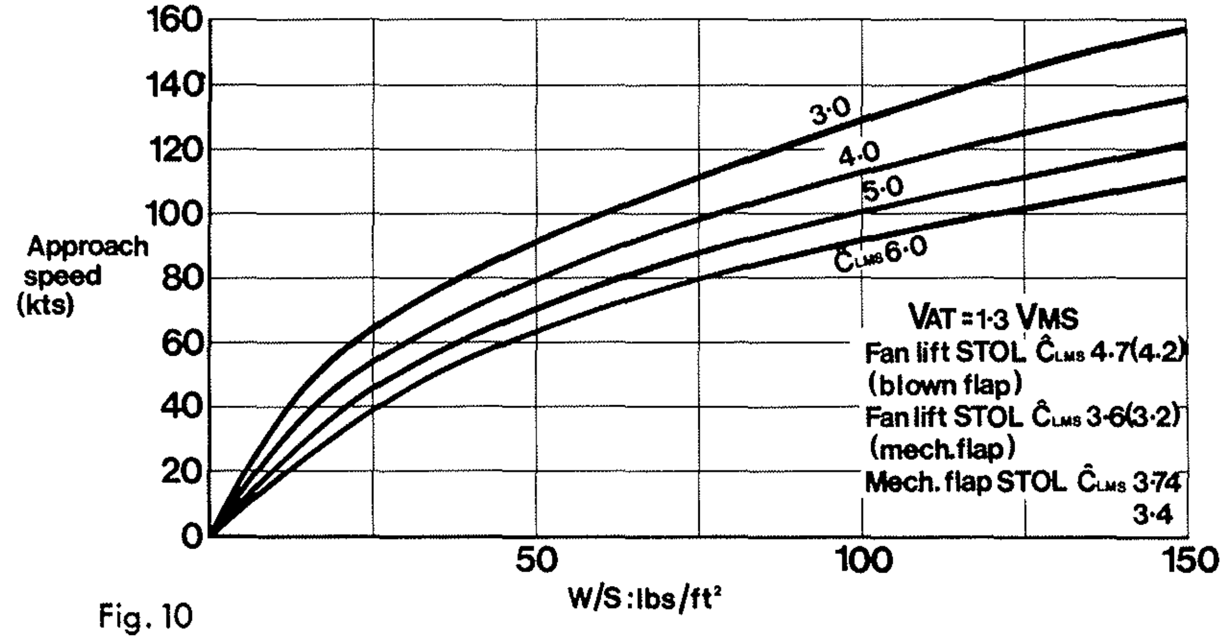


Fig. 10

Passenger comfort v Speed and Altitude

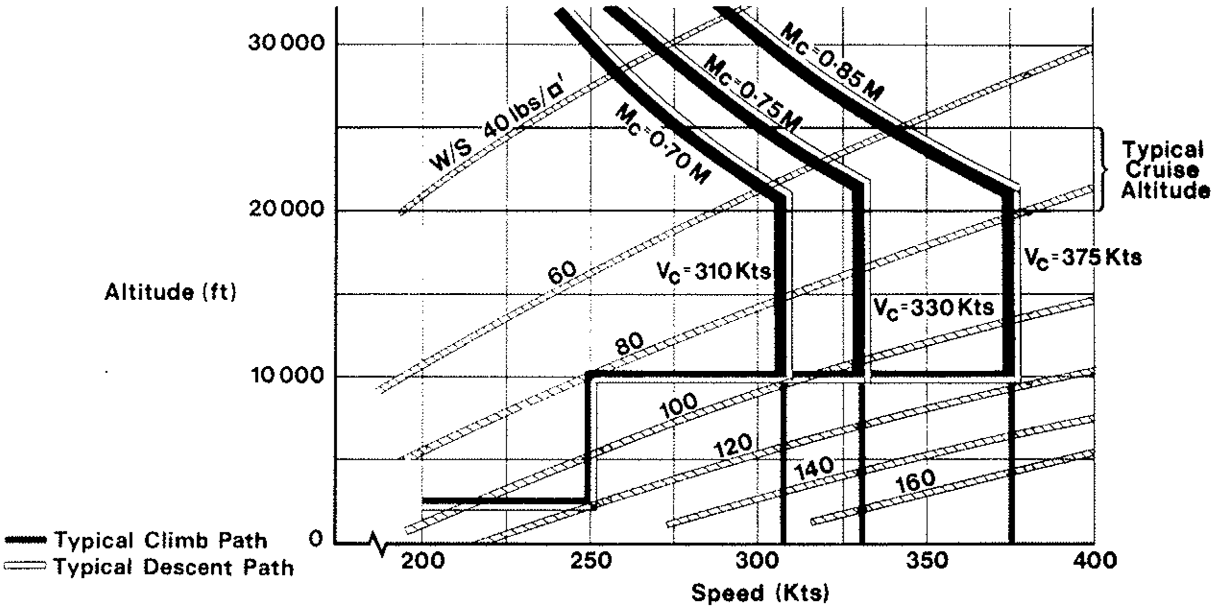


Fig. 11

STOL Approach Conditions

Approach Speed 76 knots. Approach Angle 7½°

C_L Maximum.	2·5	3·5	4·5	5·5	6·5
Wing Loading (lb./sq.ft.)	50	68	87	108	130

Approach Speed 40 knots. Approach Angle 15°

C_L Maximum.	2·5	3·5	4·5	5·5	6·5
Wing Loading (lb./sq.ft.)	13	19	25	30	36

Fig. 12

Yaw angles v field length

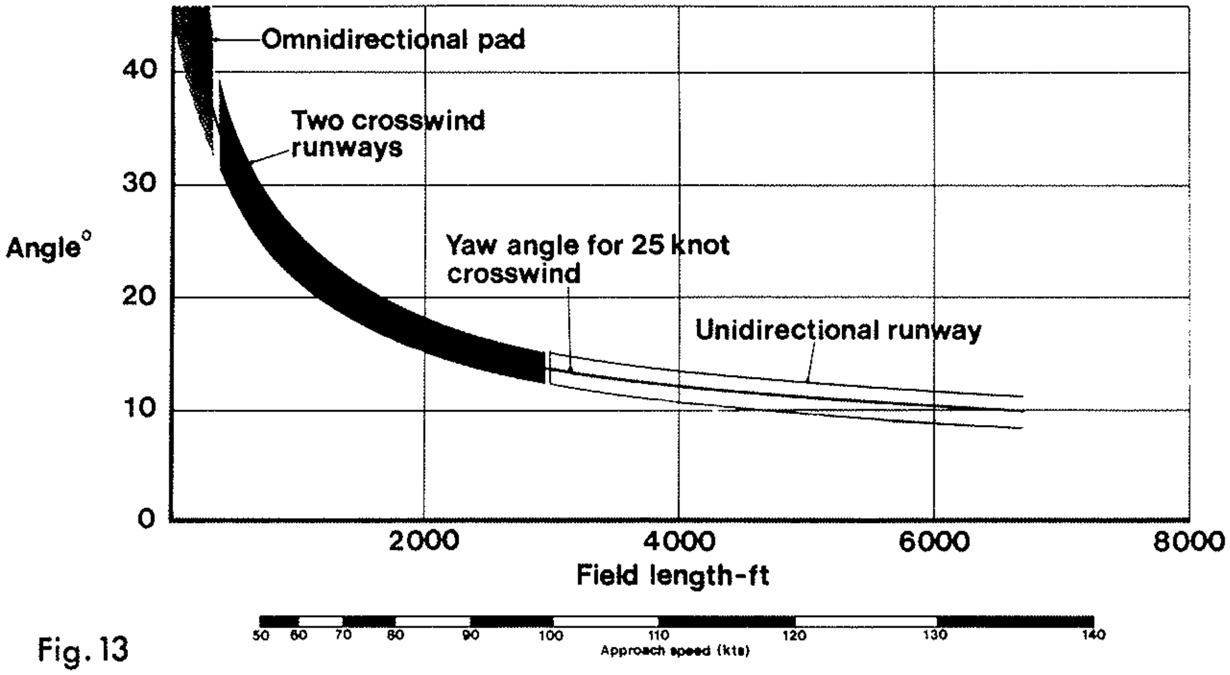


Fig. 13

Size comparison CTOL, STOL & VTOL Airports

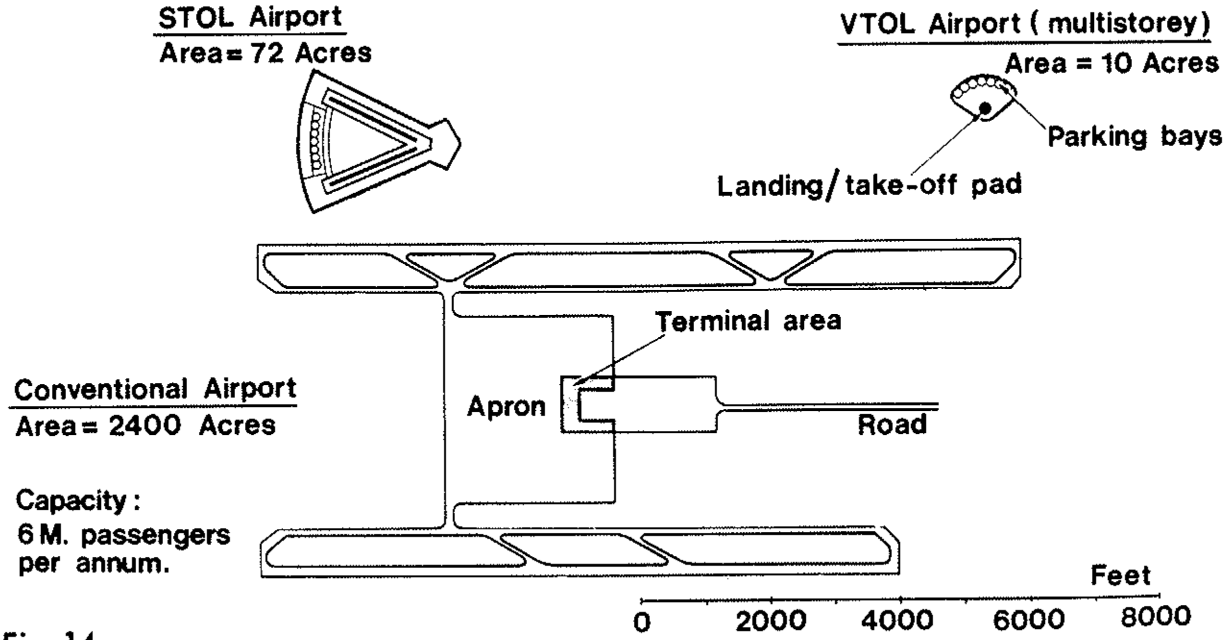
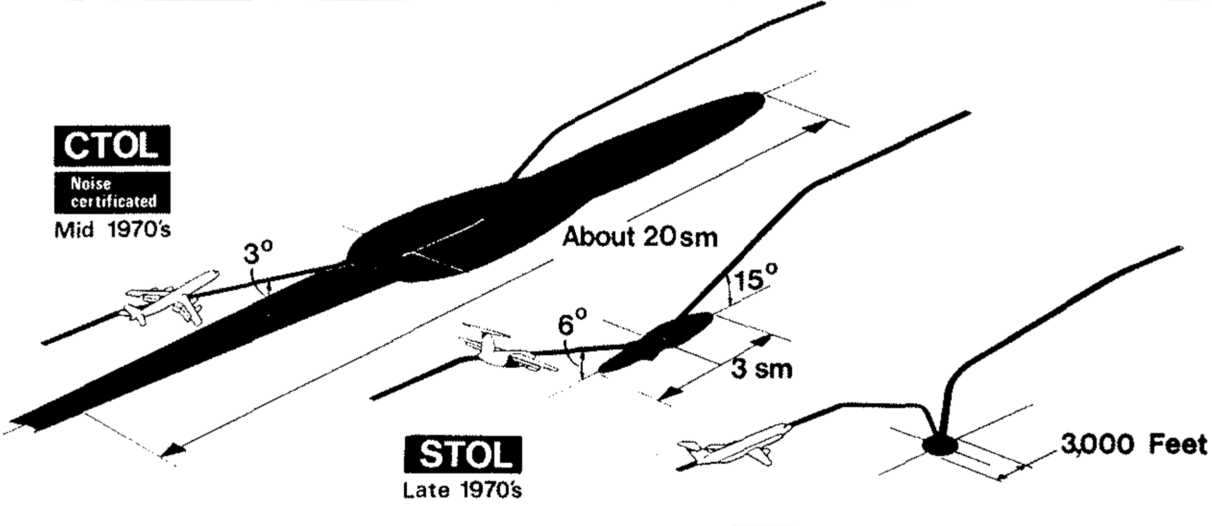


Fig. 14

90 PNdb noise footprints comparison



Area of 90 PNdb footprint (Square miles)	CTOL	STOL	VTOL
	30	1·25	0·25

Fig. 15

Cost comparisons - VTOL & CTOL airports

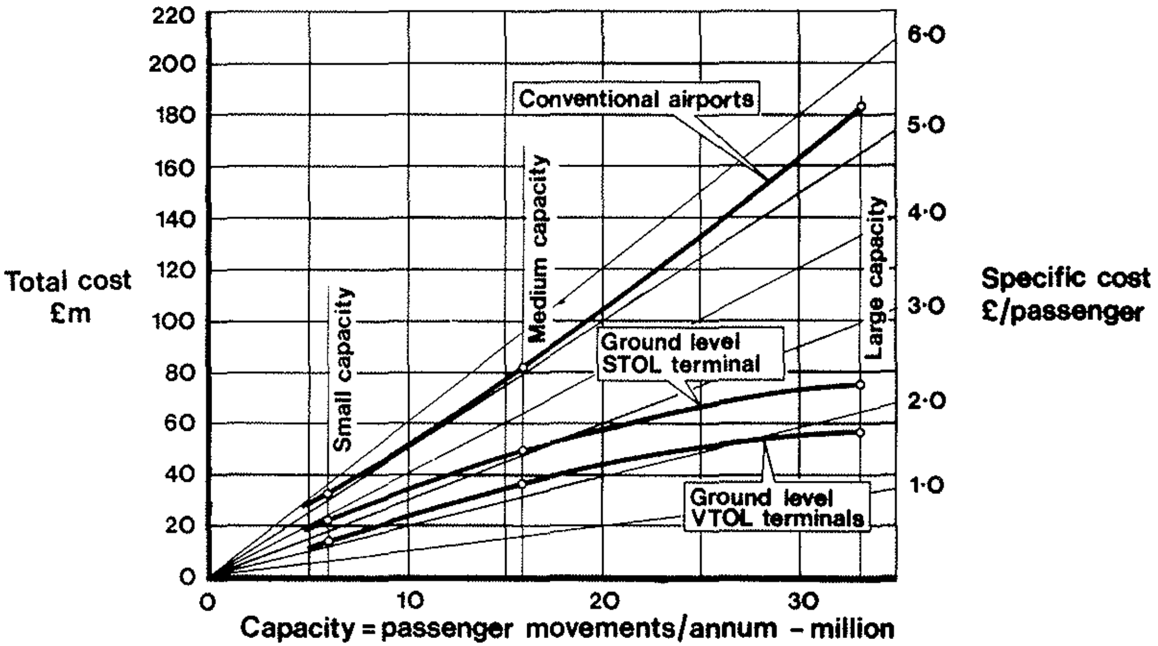


Fig. 16

Air traffic segregation with VTOL

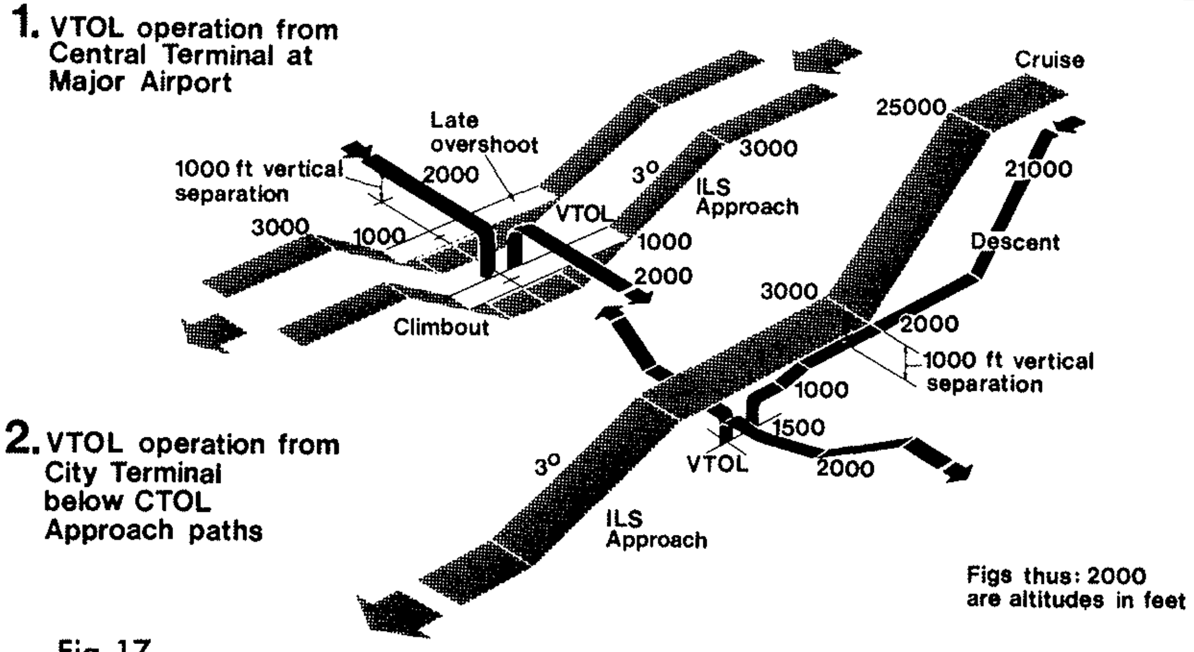


Fig. 17

Weather minima and approach aids

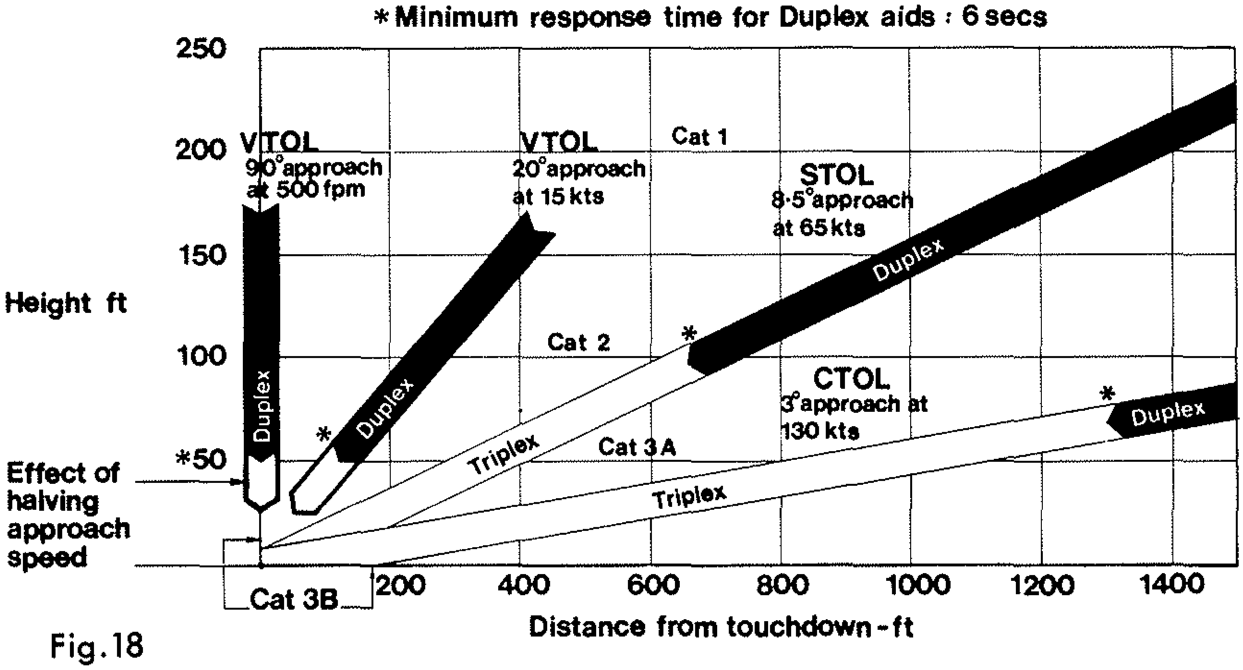
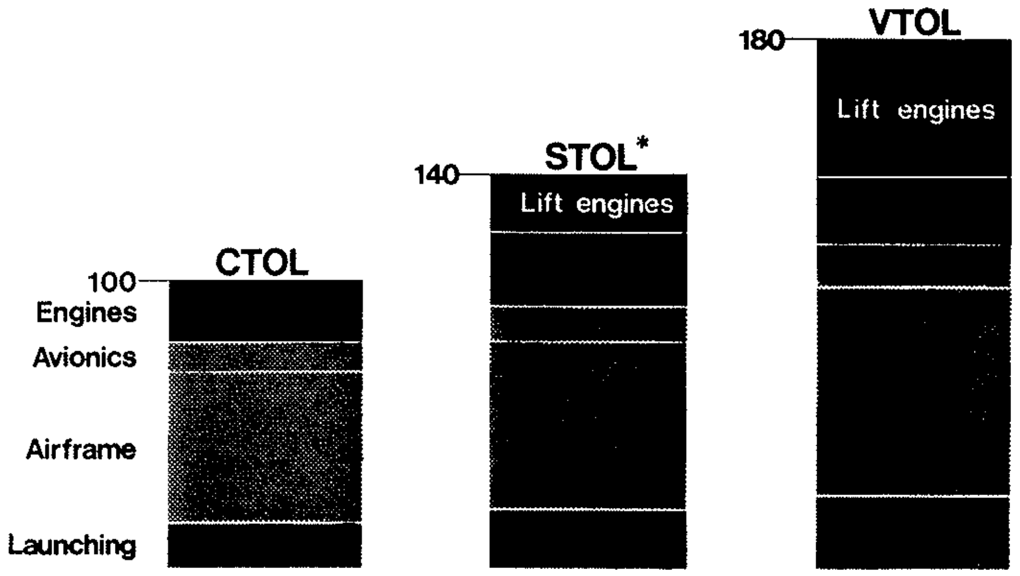


Fig. 18

Relative first costs

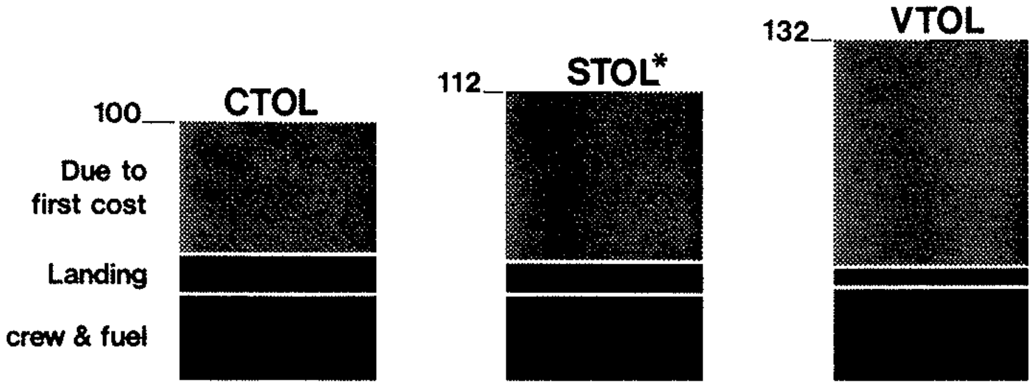


* 1500 ft field

Fig. 19

Relative direct operating costs

300 s.m. Stage



*1500 ft field

Fig. 20

Relative total journey costs

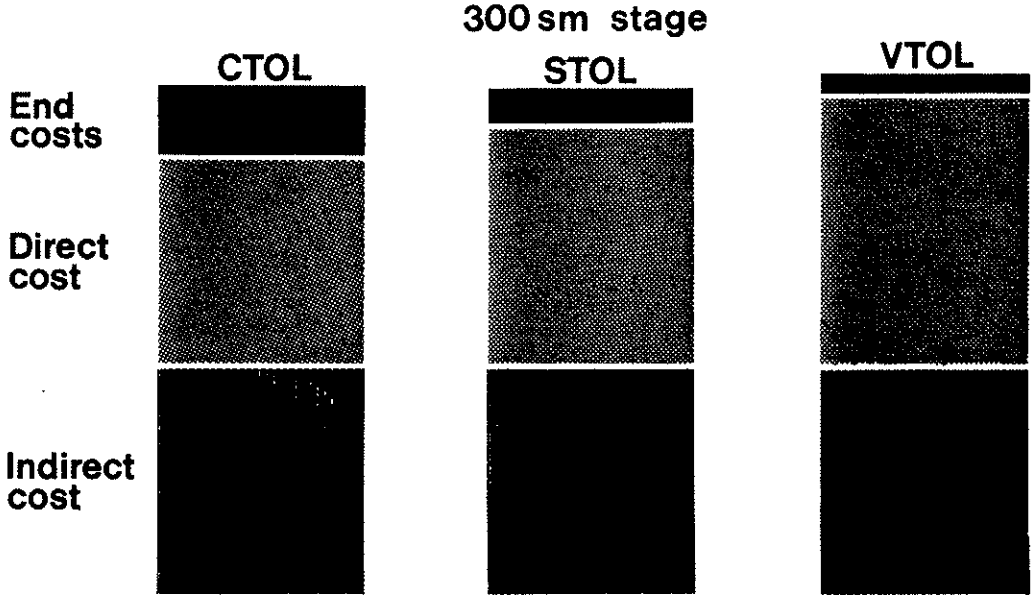
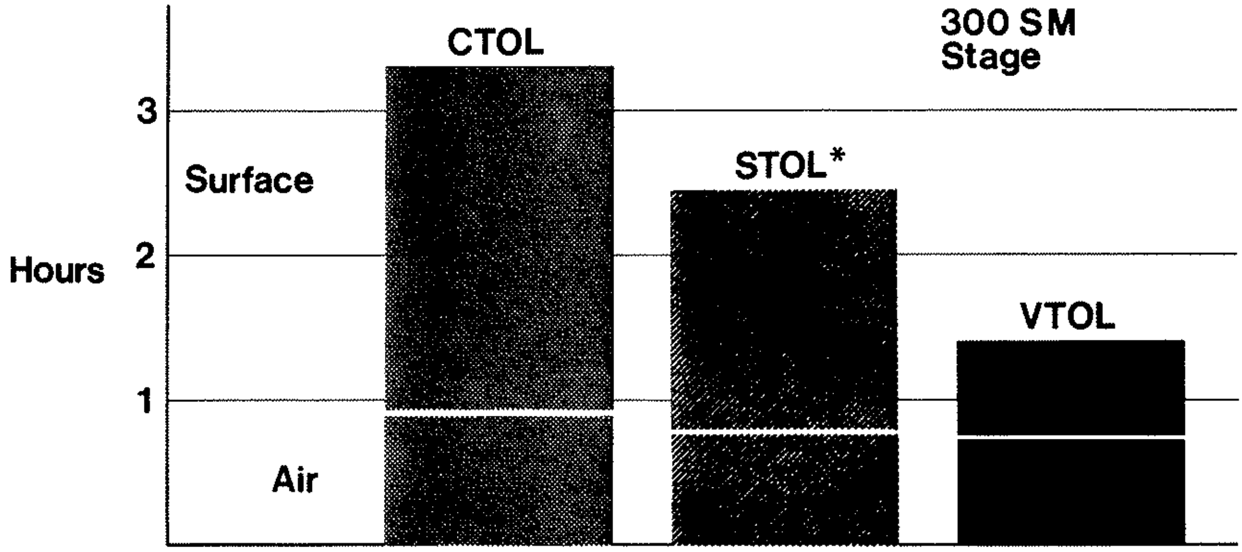


Fig. 21

Total journey time



*1500 ft field

Fig. 22

V.T.O.L. Time-Energy Relationship

Relative To 600 M.P.H. C.T.O.L.– 100 Seat Aircraft

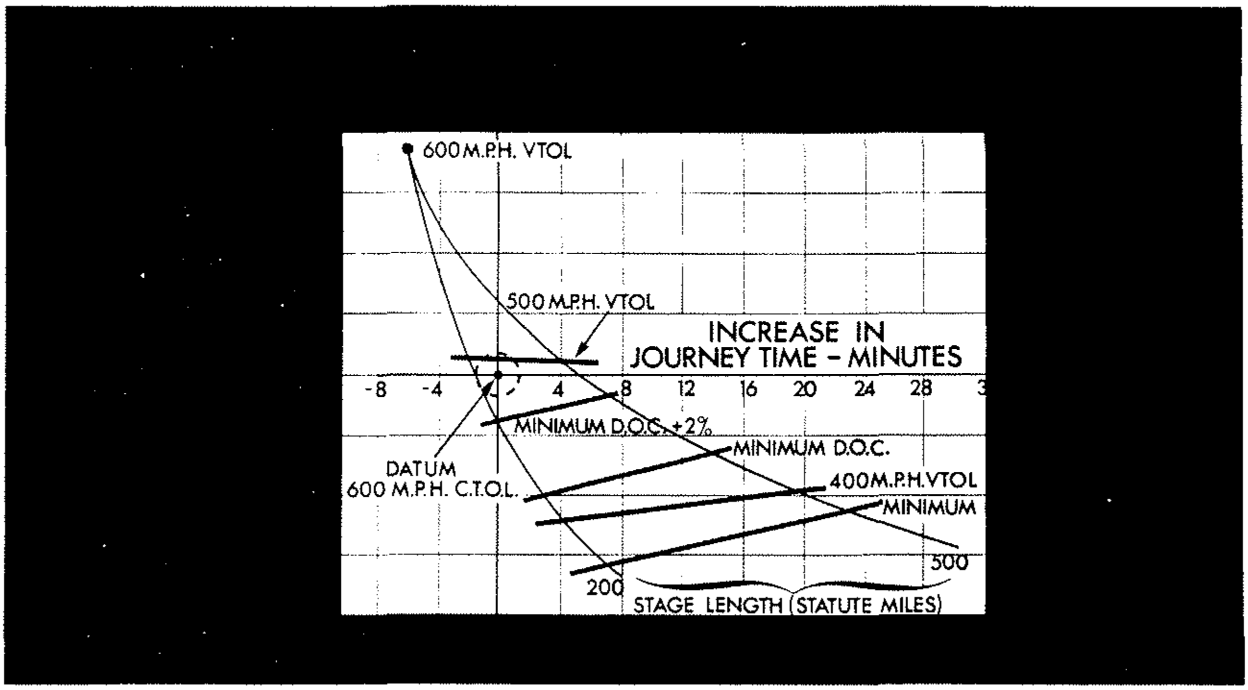


Fig. 23

Typical Aerial Tube

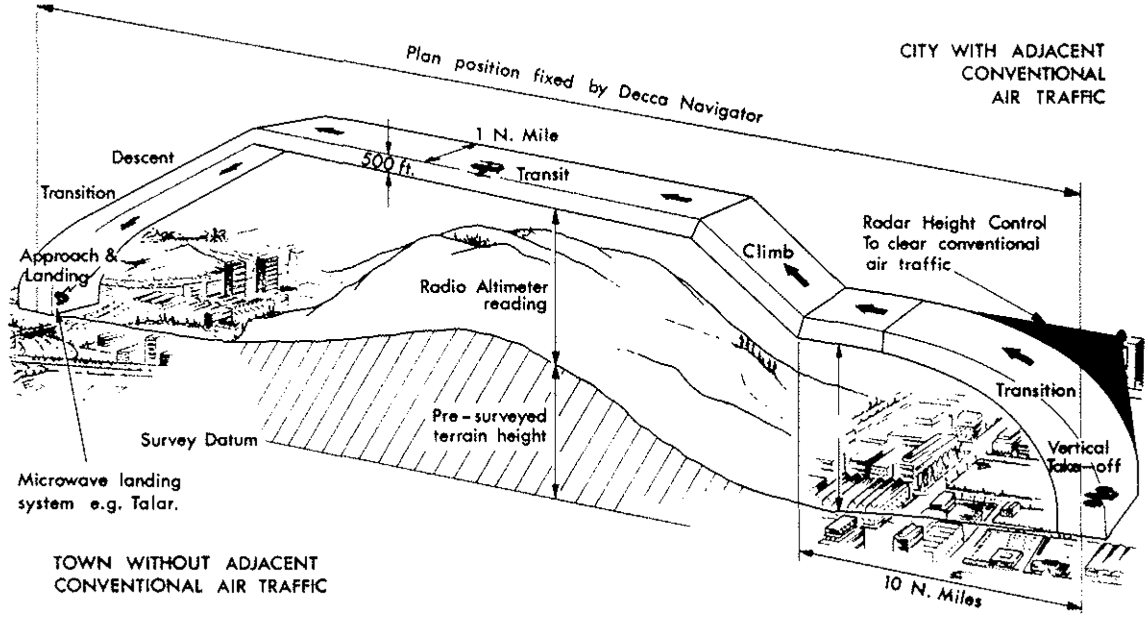
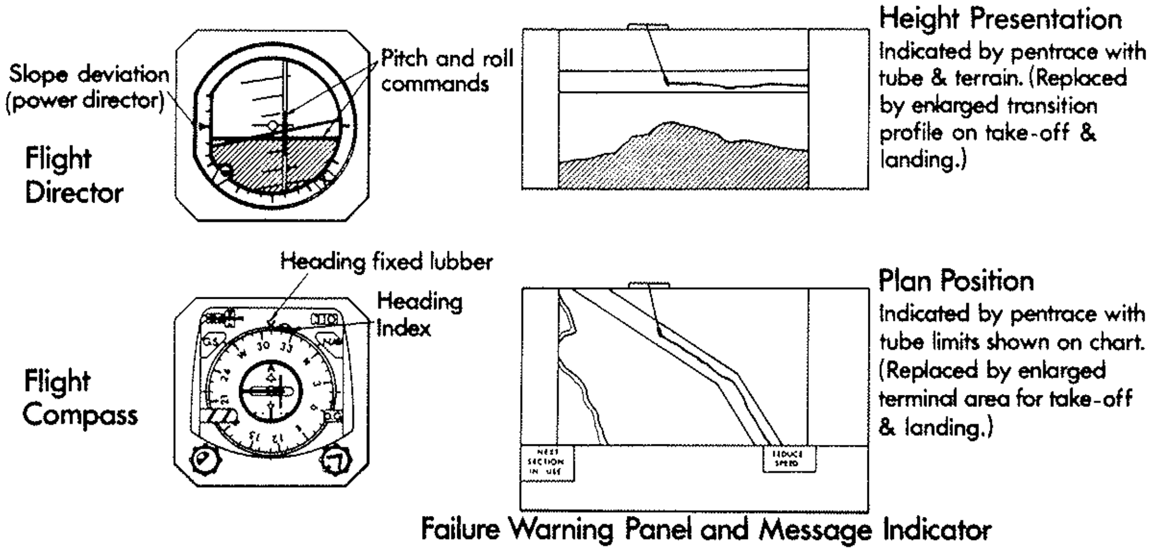


Fig. 24

Instrumentation, Position and Control Demands



Height Presentation
Indicated by pentrace with tube & terrain. (Replaced by enlarged transition profile on take-off & landing.)

Plan Position
Indicated by pentrace with tube limits shown on chart. (Replaced by enlarged terminal area for take-off & landing.)

Failure Warning Panel and Message Indicator

Fig.25

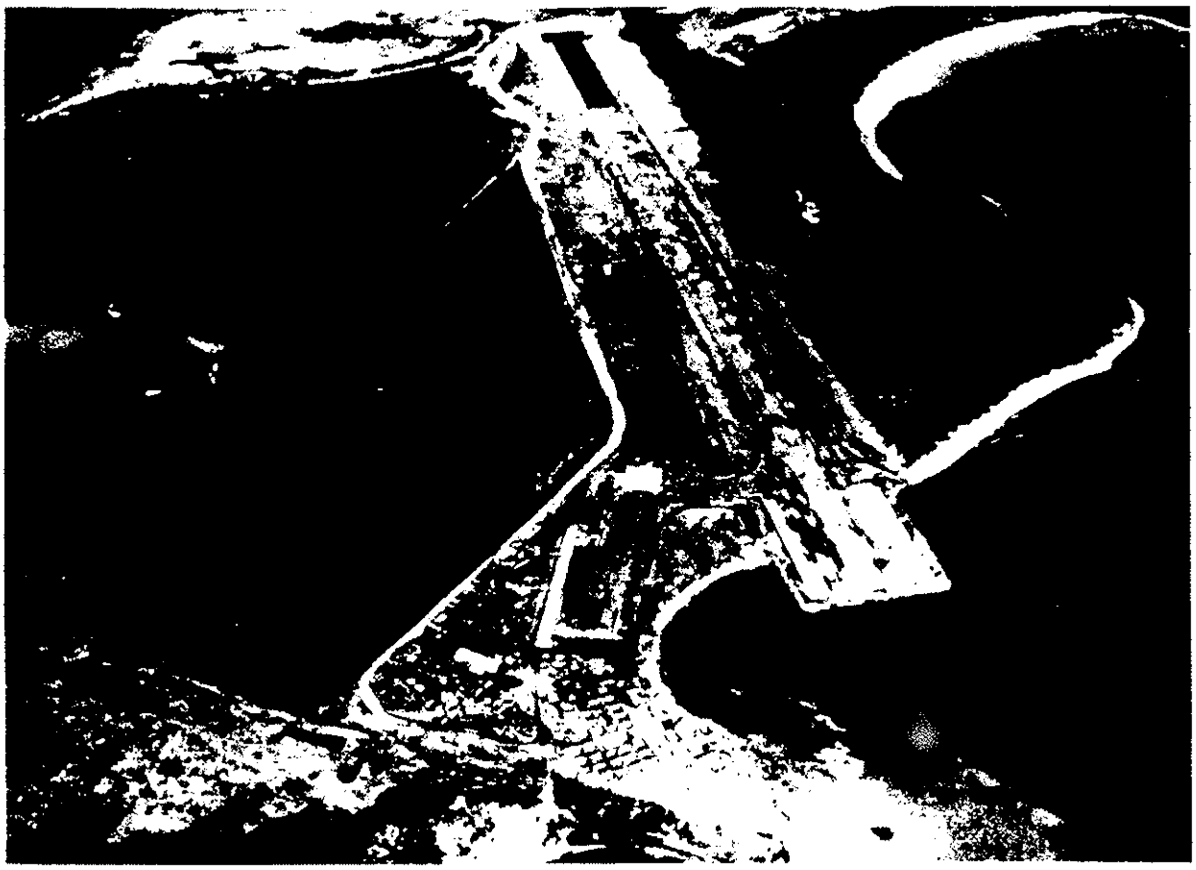


Fig.26

VSTOL Timescales

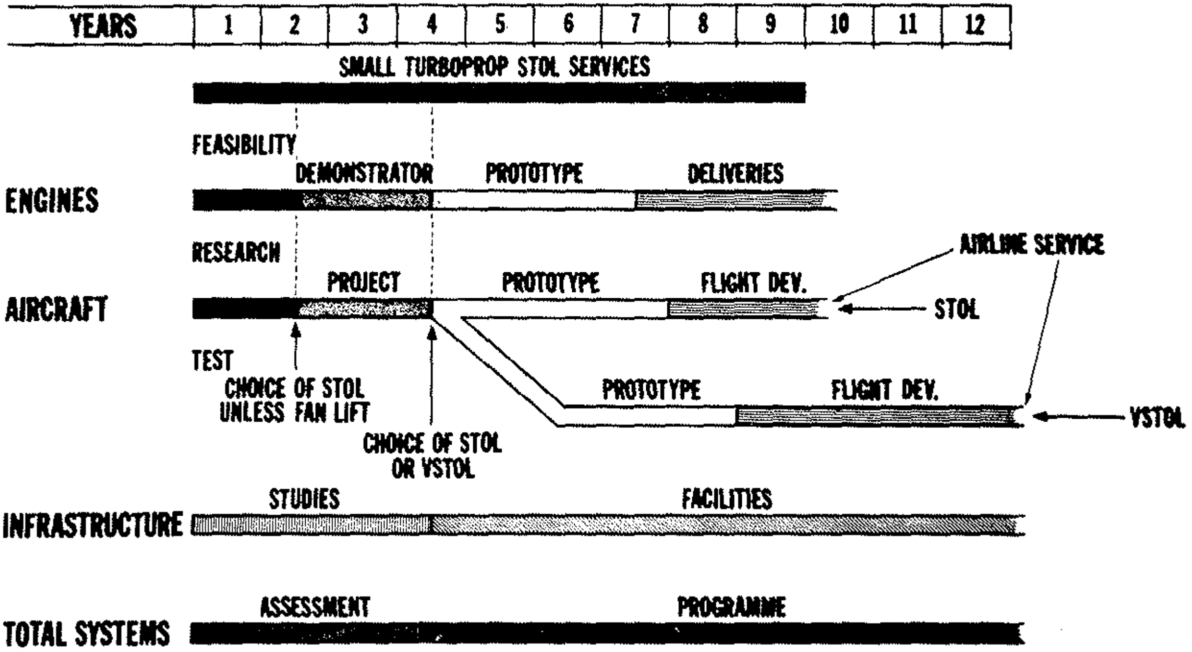


Fig. 27

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