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RESEARCHES ABOUT THE USE OF STOL AIRCRAFT IN CIVIL TRANSPORT AVIATION. SOME EXPERIMENTAL RESULTS ON A STOL AIRCRAFT MODEL

by

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RESEARCHES ABOUT THE USE OF STOL AIRCRAFT IN CIVIL TRANSPORT AVIATION

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Abstract

The development of short-haul air transport represents a very promising way of arriving at an integrated system of passenger transport capable of avoiding the ever increasing disfunctions of the non integrated systems of transport now in use. It seems important to develop a research which is intended to evaluate the most convenient limits of the expansion of air transport over short hauls and to refer the technical problems connected with the above mentioned expansion. The Institute of Aeronautics of the University of Pisa has taken into consideration the above theme developing the research in two directions which are closely connected; one relative to the technical-economic evaluation of the optimum configuration of the aeroplane and of the relative infrastructure in relation to the intensive use over short distances in Italy in 1980; the other is relative to the study of the aeromechanic behaviour of the aircraft STOL and VTOL in phases of slow flight. The technical-economic evaluation of air transport over short hauls has been developed according to the following essential points. - The prevision of the request of transport. - The definition of the technical economic and operative characteristics of the aircraft STOL and VTOL which are suitable to satisfy the request of transport. - The examination of the problem of inserting the airports for the aircraft STOL and VTOL into the urban centers they must serve. - The economic evaluation of the system of air transport over short distances. The study of the aeromechanic behaviour of the aircraft STOL and VTOL has been done developing the technique of the relative flying models in dynamic similarity. A first flying model of an aeroplane STOL with deflection of the slipstream and the boundary layer control has been realized and set-up and will be used for trial flight at the Politecnico in Milano.

I. Introduction

The development of short-haul air transport represents a very promising way of reaching an integrated system of passenger transport capable of avoiding the ever increasing disfunctions of non integrated system now in use; these disfunctions are becoming larger and larger with the development of the other components of the economy of the nations, the above systems operate in. In West European countries with an essentially industrial economy the continual increase in the volume of traffic conforms with the continue increase of population and revenue; over short hauls (i.e. distances less than 700 Kms) the above increase, mainly following the notable development of private automobile traffic is however accompanied by a constant and worrying increase in the time of travel, notwithstanding the continued increase in the maximum speed that characterizes some means of transport and in particular aircraft. The above inconvenient is caused by the inadequacy of the existing infrastructures especially in relation to the geomorphic characteristics, to the layout of the towns of the said countries and above all to the lack of a rational integration between the various means of transport.

The situation described, already bad

enough, is certainly destined to become worse with time with serious repercussions in the national and continental economy. There can be no thought of improvement except a temporary one and investing large sums of money in a scarcely productive manner. The using of the present system reveals more and more its incapability of satisfying the demand for quick transports becoming more and more pressing with the progress of the nations served.

To avoid the aforesaid inconveniences and to satisfy the rapidly increasing demand for high speed transport, it seems necessary to develop a new system of integrated transport mainly based on STOL and VTOL aircraft with large transport-power capable of operating from airports with reduced dimensions at low cost inserted in the urbanistic texture of the served towns in the immediate vicinity of the centers of traffic generation.

The possibility of utilizing in the near future STOL or VTOL aircraft for resolving the just mentioned important problems is based on the knowledge that aeronautical engineering has obtained in this field, above all in consequence of noticeable activity in research financed principally by the defence-budgets with agreements to define some configuration of STOL and VTOL adapted to the solutions of problems militarily important. The state of this knowledge allows to affirm that in Europe it could be realized with success that STOL or VTOL aircraft optimized in relation to the small distances could plausibly become operative at the end of the next decade. This possibility is, however, conditioned to a suitable research effort, adequately financed by the states interested in finding a solution to those important problems that are exposed here after. Moreover it is decisively important to fix the optimum of the operative fields for the economy of the previously stated aircraft, and of the new means of surface-transport now in a phase of noted technological development.

The object of this paper is to draw the attention to the main themes of research that need to be overcome to bring about a rational solution to the complex and multiform problems of air transport over short hauls and to exhibit successively the first results of a research made by the Institute of Aeronautics of the University of Pisa with financial contribution from C.N.R.; this research is interested in the evaluation of the utmost limits of expansion of air transport over short distances, in Italy, and to clarify the technical problems connected with the expansion above mentioned. The research previously mentioned was developed by two directives closely connected; the former related to the technical and economical appraisal of the optimum configurations adopted in the aircraft and the relative infrastructure in relation to its intensive use over short hauls in a determined geographical area, the latter relates to the study of the aeromechanical behaviour of STOL aircraft in the temporary slow flight phases. This second stage of research has been overcome, as previously clarified, by developing for the first time in Italy, the technique of powered teleguided models flying in dynamic similarity.

II. Technical and economic valuation of a system of air transport in Italy that could be in operation in 1980 over short distances.

The countries of West Europe and of the Mediterranean basin, also in consequence of a similarity especially noted in their geomorphic and urbanistic characteristics present problems of transport over short hauls (less than 700 Kms) substantially the same also if the seriousness and urgency are diverse, above all because of an exsisting difference in economic development. As these differences are certainly destined to become less in the next few years, it seems right to overcome the problem of air transport over short hauls for the whole geographic area aforesaid. However, because of many difficulties, derived above all from the not easy availability, for all the inte rested countries, in a reasonably short time, of a few data necessary for the correct posting and resolution of the problems involved, it seems to be convenient to limit the study to Italy only, a country that for geographic and urbanistic characteristic and economic development presents problems of transport over short hauls which are suf ficientely representative of the problems of the geographic area under consideration.

It has been tried to develop a sufficiently general method for the economic evaluation of the system, a method applicable also in diverse cases than those examined, in the following essential points:

1) Prevision of the total demand to transport passengers over short hauls up to 1980 and its distribution among the different means of transport on the assumption of existing air transport system optimized over short hauls.
2) Definition of the technical economic and operative characteristics of some particular STOL and VTOL aircraft; capable of satisfying the demand pre stated with a prearranged level of safety.
3) Examination of the problem of building airports for STOL and VTOL (STOL and VTOL-PORTS) within the urban network of the centers to be served with particular attention to noise and efficient operation needed.
4) A technical and economic evaluation of the infrastructure necessary to guarantee the operative characteristics requested.
5) Technical and economic evaluation of the system of transport and comparison of different possible solutions STOL and VTOL.

The following study is developed by applying the methods previously stated and must be considered as an approach nearest to the proposed problem on the basis of plausible hypotheses which are necessary to fill in the blanks in information indispensable for the correct posting of work that it has not been possible to find because of the long time necessary for and the limited number of researchers employed in the research. Up to now it has not been faced the problem of integrating the various systems of transport, indicated firstly as a basic concept, considering that a rational solution could be obtained only in a second phase of optimization of the complete system of transport over short hauls: the concepts informing the above written optimization have become already objects of a finished study published by this Institute [1].

II.A - Prevision for a demand for transport in Italy in the next 12 years

There is a tentative to evaluate the demand for transport of passengers in Italy up to 1980 and the distribution of the said demand among the diverse means, supposing there is in existance a system of air transport optimized over short hauls of the type indicated in the introduction.

This prevision has been based on the following considerations and hypotheses:

a) In a said geographic area the volume of global traffic of passengers depends essentially on the number of inhabitants and their revenues. In particular in central European countries of medium and high revenue one could notice that the ratio of the work of transport made by public means

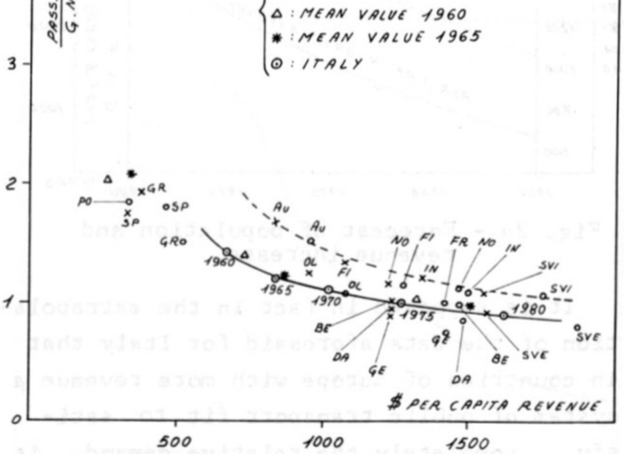


Fig. 1 - Ratio of the work of transport made by public means to G.N.P. versus per capita revenue in West Europe in 1960 and 1965.

of transport in a given nation in a said year to the gross national product diminishes with the increasing of the revenue per head with a law sufficiently clear when a group of nations with a sufficiently uniform economy, geographic and population is considered.

Confronting the data on traffic, revenue and population for various countries with an income per head equal to or more than in Italy in different years has become possible to identify, Fig. 1, a law plausible for Italy and, on the basis of well known previsions on the development of revenue and of the population [2,3] to evaluate the work of annual transport by public means up to 1980. To identify the above function in the aforesaid manner is certainly a cautious proceeding in relation to the potential traffic over short hauls by plane since it is prudently supposed that the introduction of new systems of transport does not augment the competition of public transport as against that of private, but produces only a diverse distribution of the volume of traffic among the diverse means of public transport.

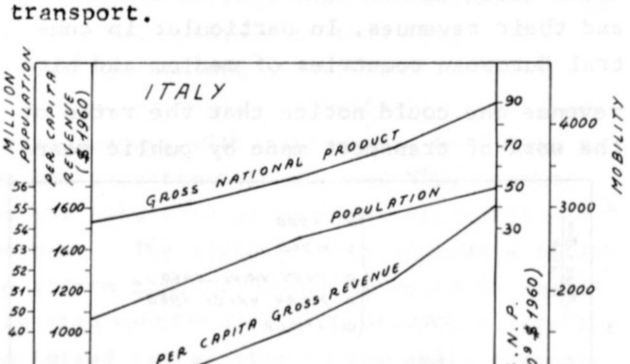


Fig. 2a - Forecast of population and revenue increase.

It is supposed in fact in the extrapolation of the data aforesaid for Italy that in countries of Europe with more revenue a system of public transport fit to satisfy completely the relative demand, is available. Anyhow it appears clear that a new system of integrated public transport more efficient than the existing one, will

	1960	1965	1970	1975	1980
POPULATION (MILLIONS)	49,6	51,6	53,5	54,8	56
PER CAPITA REVENUE ($ 1960)	670	828	1020	1270	1620
G.N.P. × 10⁶ ($ 1960)	33,27	42,7	54,5	69,6	91
Pass.Km Public Means / G.N.P. × 10⁶	1,42	1,2	1,12	1	0,9
PASS. Km PUBLIC MEANS (BILLIONS)	47,2	51	61	69,6	
INHABITANTS / Nº OF CARS	25	9	7	6	5
Nº OF CARS (MILLION)	1,99	5,47	7,65	9,15	11,2
PASS. FOR CARS	2	2	1,8	1,8	1,8
AVERAGE DISTANCE PER YEAR (Km)	7000	7000	7000	7000	7000
PASS.·Km CARS (BILLIONS)	28	76,5	96,5	115	
PASS.·Km TOT. (BILLIONS)	75,2	127,5	157,5	184,6	223
MOBILITY ALL THE MEANS PASS. Km/INHABITANTS	1570	2470	2950	3360	3980
% PASS. Km PUBLIC MEANS / PASS. Km (TOTAL)	62,7	40	38,7	37,8	36,8
% PASS. Km CAR / PASS. Km (TOTAL)	37,3	60	61,3	62,2	63,2
MOBILITY PUBLIC MEANS PASS. Km/INHABITANTS	950	990	1140	1300	1460

Tab. 1 - Forecast of revenue and traffic for Italy.

be in a position to compete with private automobile transport between cities because of the ever increasing difficulties revealed in this means of transport for the progressive saturation of the road infrastrctu re especially in the proximity of the large urban centres.

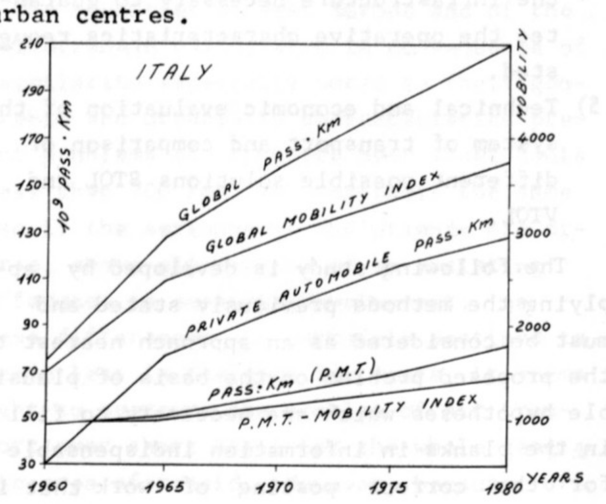


Fig. 2b - Forecast of traffic increase for Italy.

b) It has been supposed that the effective traffic on the various connections is divided like the potential traffic; to calculate this formula $N_o = P_1 P_2 / d^2$ has been used.

It has not been thought suitable to introduce into the above mentioned formula corrective coefficients, which take into account the particular economic geographic and social factors which influence the amount of traffic between two centres, since it is very difficult to evaluate correctly coefficients of this type which are valid for the situation of hypothetical traffic in the foreseen period. This method of operating may bring one to overestimate the volume of traffic on some connections and underestimate it on others; the formula gives reliable results when it is used to evaluate the average distribution of the volume of traffic as a function of the distance. The method shown, as it will be explained better later, individuates these connections, among all those possible, (503 out of 4232), on which the volume of traffic is large enough to justify the introduction of air transport and give a first approximate picture of the air network clarifying in which direction a very complex and expansive research must be directed, to determine a distribution of the volume of traffic on the single hauls which corresponds to the geographical economic and social situation of the centres served.

c) The division of passenger traffic among the different means of transport in a certain geographical area, supposing there is a free choice on the part of the traveller, is essentially a function of the total cost of the journey (tariff class+travel time value for business journeys; of the simple tariff for all the others).

It is difficult to establish a suitable representation of the above said function, above all because one has no direct experience of the problem and has no data on the effects that the introduction of this new means of transport might have on the choice made by the persons served.

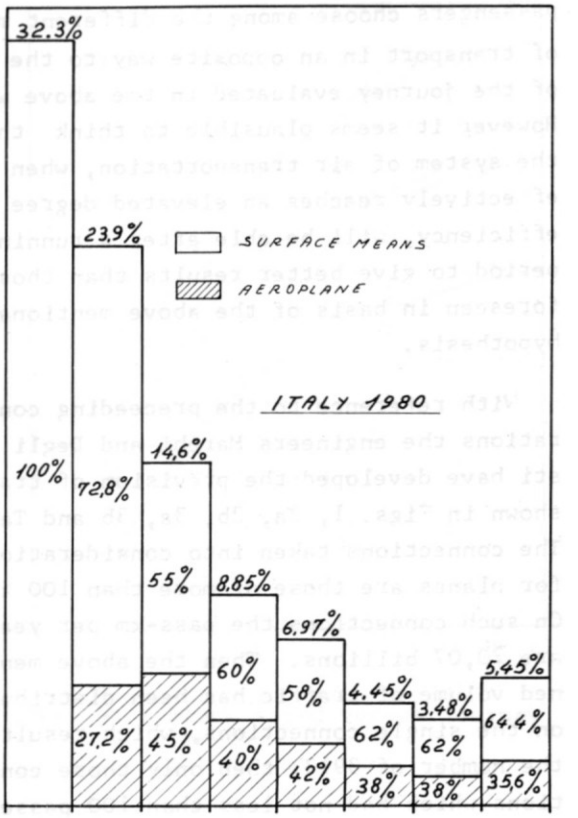


Fig. 3a - Distribution of public means traffic versus journey length.

Past experience has shown that the movement of passengers from a less efficient means of transport to a more efficient one, takes place gradually; even if after a certain interval of time, the more efficient means prevails. In impossibility of affronting this problem in a rational way, a very simple hypothesis has been formulated, and that is that in every journey length the

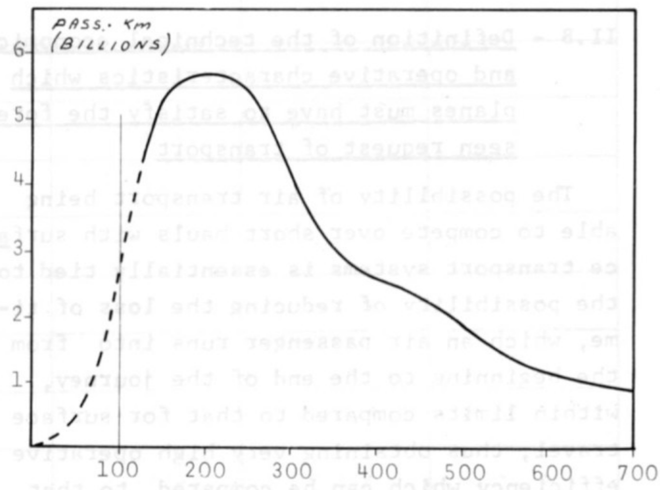


Fig. 3b - Distribution of air-traffic versus journey length.

passengers choose among the different means of transport in an opposite way to the cost of the journey evaluated in the above way. However it seems plausible to think that the system of air transportation, when it effectively reaches an elevated degree of efficiency, will be able after a running-in period to give better results than those foreseen in basis of the above mentioned hypothesis.

With reference to the preceeding considerations the engineers Marchi and Degli Esposti have developed the prevision of traffic shown in Figs. 1, 2a, 2b, 3a, 3b and Tab. 1. The connections taken into consideration for planes are those of more than 100 kms. On such connections the pass-km per year are 20,07 billions. Then the above mentioned volume of traffic has been distributed on the single connections, which result in the number of 3913; then only those connections which had not less than 100 passengers per day have been taken into consideration. In this way the number of connections and of pass-km are reduced to 503 and to 8,93 billions. The volume of traffic which remains could probably be recuperated, at least in part, through indirect connections when a rational organization of the time table makes it possible to eliminate excessive waiting in the intermediary stops. However this volume of recuperable traffic has not be taken into consideration.

II.B - Definition of the technical economic and operative characteristics which planes must have to satisfy the fore seen request of transport

The possibility of air transport being able to compete over short hauls with surface transport systems is essentially tied to the possibility of reducing the loss of time, which an air passenger runs into from the beginning to the end of the journey, within limits compared to that for surface travel, thus obtaining very high operative efficiency which can be compared to that of surface transport systems.

To obtain a consistent reduction of lost time it is necessary above all that the airport be as near as possible to the center of origin of the traffic; it is also necessary to assure an adequate integration of air transport over short hauls with systems of surface transport or systems of air transport over medium length or long distances, which almost certainly in the near future will have to use airports of large dimensions no nearer than the present ones are to large centers. To bring the operative capacity of air transport over short hauls to a satisfactory level it is necessary to arrive at conditions of safety to accept minimums of visibility and maximums of atmospheric turbulence less restrictive than that now in use and however adequate to the metereological ambient of each airport.

The nearing of the airport to the origin center of the traffic is made easier by using STOL and VTOL aircraft for reduced dimensions of the runways necessary for the take off and landing. Moreover the noise characteristics of these aircraft are less unfavorable than those of the present conventional aeroplanes, in as much as for the aircraft STOL and VTOL climbing and descending trajectories are possible at steep slope.

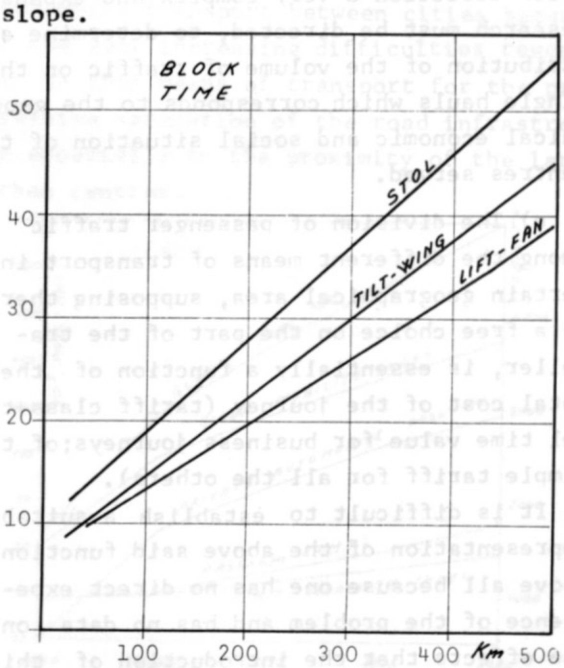


Fig. 4a - Block time versus journey length.

Finally consistent reductions of the minimums of safety visibility are consented by the low speed at which the aircraft STOL and VTOL approach the runway. On the basis of the preceeding considerations the characteristics which the above mentioned aircraft STOL and VTOL should have to satisfy the above mentioned request of transport have been defined and studied in a first approximation . The following three types of aircraft have been taken in consideration:

1) STOL aircraft with slipstream deflection able to take off in 300 m. overrunning an obstacle of 15 m. with the arrest of one engine at the critical point.
2) VTOL TILT-WING aircraft.
3) VTOL LIFT-FAN aircraft.

The choice has been limited to these three types from among the numerous others because we know their performance and cost calculated on a basis directly comparable[4]. The characteristics offered by the above three aircraft make it possible to cover a vast field of performance.

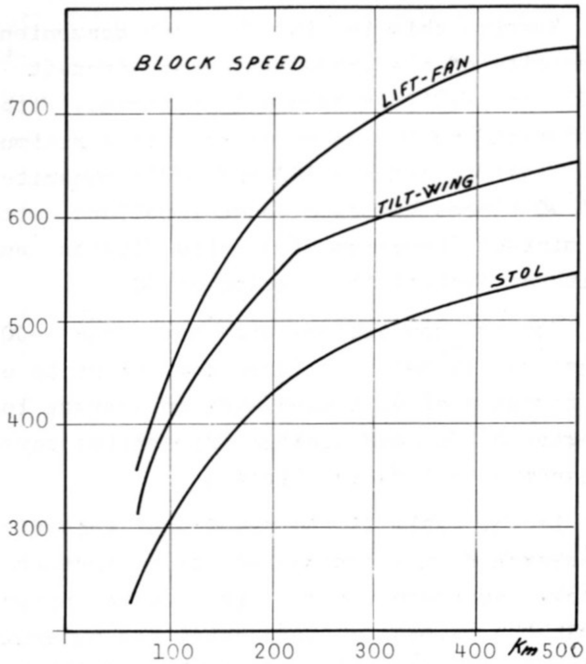


Fig. 4b - Block speed versus journey length.

	LENGTH	Number of City Pairs Connections	Mean Number of pass/day	Number of pass/years 10^{-3}	$\frac{\text{Pass.Km}}{\text{year}}$ 10^{-6}	Mean Number of Flights in a day
100÷400 Pass/Day	100÷200	232	187	15880	2295	8
	200÷300	130	187	8862	2220	8
	300÷400	49	171	3067	760,5	7
	400÷500	16	149	870	397	6
	500÷600	8	131	336,5	179	6
	600÷700	2	194	148,35	98,2	8
TOT.	-	437	-	29163,85	5929,7	-
MORE THAN 400 Pass/Day	100÷200	46	714	11980	1795	11
	200÷300	17	632	3938	984	10
	300÷400	2	455	333	113,5	7
	400÷500	1	655	239	112	10
TOT.	-	66	-	16490	3004,5	-
GEN. TOT.	-	503	-	45653,85	8934,2	-

Tab. II - Characteristics of the connections with more than 100 passengers in a day.

Bearing this in mind the most convenient capacity of the above mentioned aircraft STOL and VTOL has been estabilished. With reference to the connections with a minimum of pass/day between 100 and 400 a capacity of 40 places has been found excellent, with a minimum frequency of 4 daily flights and with an average load factor of 60%.

For the connections with more than 400 pass/day it has been found convenient to use a capacity of 90 places with an average load factor of 70% and minimum frequencies corresponding to 6 daily flights.

In the table II the results of this first research of the optimum solutions indicated above have been resumed: it must be noted that the necessary frequencies are numerous enough to consent a distribution of flights during the day, which is suitable for a service of this type. The maximum operative range has been fixed up to 500Km for the above mentioned aircraft. This value seems to be the most convenient, as it has been noticed that most of the connections exceed 500 Km. Such a value of the autonomy consents direct services in almost all the connections and two flights over shorter distances without intermediary refuelling.

Once the above parameter was fixed it has been possible to determine, as a function of the journey length, all the other flight characteristics and the direct operative costs, finding the necessary information by opportunely elaborating the data given by the pu

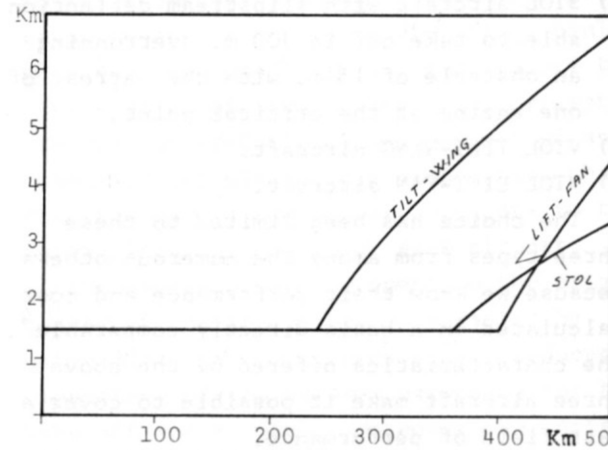


Fig. 4c - Optimum cruise height.

CHARACTERISTIC	STOL		TILT-WING		LIFT-FAN	
	40 seat	90 seat	40 seat	90 seat	40 seat	90 seat
WEIGHT EMPTY (Kg)	10700	17300	13300	22700	12700	19900
WEIGHT EMPTY EQUIPPEL (Kg)	11000	17800	13600	23400	13000	20200
PAY LOAD 40-90pass.+10%cargo	3780	8500	3780	8500	3780	8500
FUEL 500 Km - Kg	1280	2500	1580	2700	3200	5300
RESERVES (100 Km cruise + a half hour)	700	916	730	1320	1390	2520
MAX. T.O. WEIGHT (Kg)	16760	29716	19690	35920	21370	36520
WEIGHT TO POWER OR THURUST RATIO	1,62	1,62	1,22	1,22	1,76	1,71
POWER PLANT	4x2600	4x4600	4x4000	4x7400	4x3400	4x5340

Tab. III - Aircraft characteristics.

blication [4] which contains all the technical and economic data relative to the aircraft STOL and VTOL which were examined in the present work; these aircraft have been optimized for an ample interval of pay-loads. The direct operating costs which result from [4], vary very little in the field of stage length comprised between 80 and 800 Km: the absolute minimum of operative cost is had in corrispondence with the maximum stage length, equal to 800 Km; it has been therefore necessary to reelaborate the data furnished by [4] to take into account that in the case of the present work the assumed maximum stage length is 500 Km instead of 800. This re-elaboration has been done on the basis of the hypothesis that the above mentioned optimum solution remains such when the corresponding pay-load is increased in quantity equal to the the weight of fuel necessary for 300 Km cruising (that is the

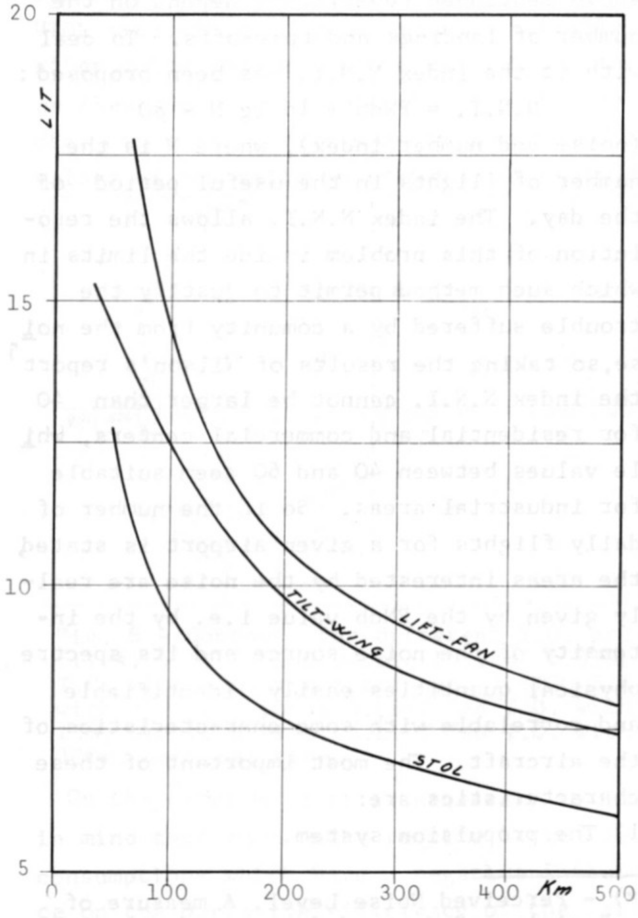
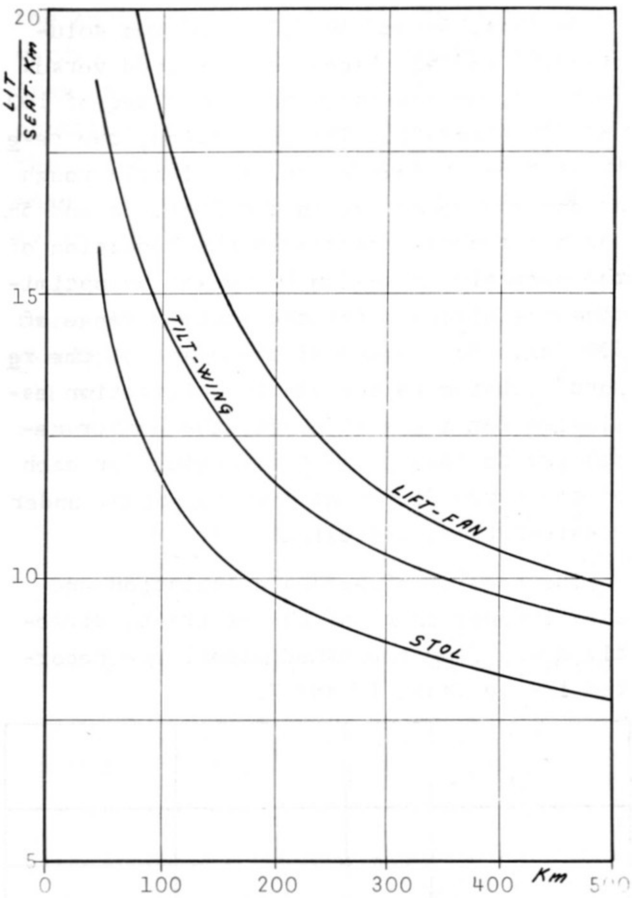


Fig. 5a - Direct operating cost-90 seats aircraft-quantity of produced unity = 100.



Fif. 5b - Direct operating cost - 40 seats aircraft - Quantity of produced unity = 100.

difference between the maximum range in the two cases). This hypothesis seems plausible as the plot of cost versus range is quite flat and the value of the ratio of the weight of substituted fuel to the total weight of the aeroplane is modest (about 1%). The results, which were got in such a way of operating, are in Tab. III and in Fig. 4a, 4b, 4c where the characteristics of the STOL and VTOL aircraft under examination are summarized.

AIRCRAFT	90 SEAT	40 SEAT	TOTAL NUMBER
STOL	55	254	309
TILT-WING	40	192	232
LIFT-FAN	36	171	207

Tab. IV - Number of the aircraft necessary to satisfy the foreseen request of transport.

In Figs. 5a and 5b D.O.C. of two solutions (90 and 40 places) are plotted versus seat-Kms, on the assumption of a set of 100 and 200 aircraft. The assumption, the re-elaboration is founded on, is clearly rough as one can point out in the Figs. 5a and 5b. For the shortest distances the reduction of the operative costs could be got by optimizing the aircraft for the maximum range of 500 Kms. By the use of the chart of the report[4] related to the yearly utilization estimated for these aircraft, the number necessary to accomplish the service for each of the three different configurations under consideration, was calculated.

The results of such a calculation and the fly-away costs of the aircraft, directly drawn from the named paper, are reported in the Tabs. IV and V.

AIRCRAFT	SET	40 SEAT	90 SEAT
STOL	50	2485	3115
	100	1705	2130
	200	1210	1558
TILT WING	50	3140	4430
	100	2140	3040
	200	1570	2020
LIFT FAN	50	3465	4590
	100	2450	3280
	200	1852	2490

Tab. V - Fly-away costs of aircraft for different set of produced unity (millions of Lit.).

II.C - The VTOL and STOL airports and their insertion in the urban texture of the served centers

The convenient insertion of the airports into the urban texture of the served centers at short distance from the traffic origin, is one of the most important problems which must be faced to have an efficient transport system on short ranges. The main difficulty of the problem mainly comes from the noise produced by the aircraft during take-off and landing; a very intense noise has a negative influence on most of the human activities and therefore makes the area just around the airport quite unsuitable to be used for residential and commercial purposes. The size of the above mentioned area can be found with a quantitative evaluation of the annoyancefor a person intent on a given activity from a given noise source as a function of the distance between the source and the person. A lot of experimental methods to evaluate the annoyance produced by the noise have been proposed to deal with the characteristics of the noise source in different ways. When the source is an aircraft the annoyance measure unit is generally the Pndb*.

More and more the noise itself is repeated less and less is the capability of a comunity to bear an intermittent noise; the above mentioned repetitions depend on the number of landings and take-offs. To deal with it the index N.N.I. has been proposed:

$$N.N.I. = PNdb + 15 \lg N - 80$$

(noise and number index), where N is the number of flights in the useful period of the day. The index N.N.I. allows the resolution of this problem inside the limits in which such methods permit to justify the trouble suffered by a comunity from the noise, so taking the results of Wilson's report[5] the index N.N.I. cannot be larger than 40 for residential and commercial centers, while values between 40 and 60 seem suitable for industrial areas. So if the number of daily flights for a given airport is stated, the areas interested by the noise are really given by the PNdb value i.e. by the intensity of the noise source and its spectre physical quantities easily identifiable and correlable with some characteristics of the aircraft. The most important of these characteristics are:

1) The propulsion system.

*) - Perceived Noise Level. A measure of "noisiness" derived from sound pressure levels in frequency bands, by a procedure described by K.D. Kryter [13]. PNdb is the unit of perceived noise level.

2) The power or the thrust developed or, what is the same, the maximum weight at take-off as there exists a well defined relation between these parameters for a given kind of aircraft.
3) The slope opportunely defined by the paths performed by the aircraft during landing and take-off.

If one wants to compare CTOL, STOL, VTOL aircraft, when the pay-load is the same, it is easy to find that VTOL and STOL use larger powers and so are sources of more intense noise. However STOL and VTOL aircraft can perform steeper paths during landing and take-off than CTOL even if using shorter runways; so after all the areas interested by a noise more intense than a prefixed value are less large for STOL and VTOL aircraft than for CTOL ones. The optimization of the paths from the point of view of noise annoyance minimization is so a fundamental problem; from this point of view VTOL aircraft can, at least theoretically, offer quite good annoyance characteristics as they can perform part of take-off landing paths vertically even if they have high values of the ratio power/pay-load. (Fig.6).

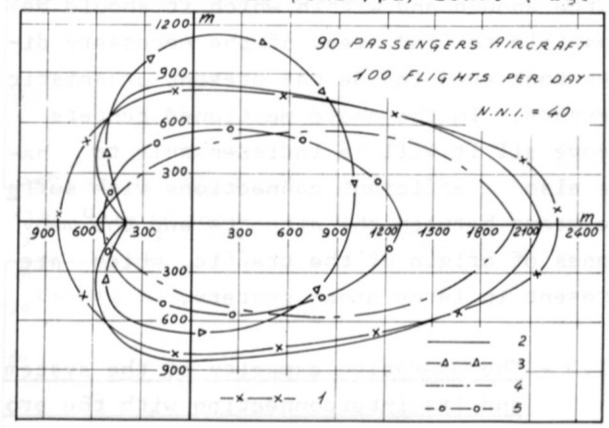


Fig. 6 - Contours for different T.O. profiles. 1.TILT WING vertical rise. 2.STOL T.O. with straight climb out. 3.STOL T.O. with climbing turn. 4.LIFT FAN T.O. with 15m. vertical rise. 5.LIFT FAN T.O. with 300m. vertical rise.

On the other hand it is necessary to bear in mind that such paths require large fuel consumptions which have a negative influence on the operative efficiency of the aircraft and involve complex safety problems.

The path slope may so be influenced by the environment, as it will be seen afterwards. So the final path choice comes out from an equilibrated compromise between the opportunity of reducing as much as possible the extension of the areas interested by an annoying noise and the necessity of safety and fuel economy.

In Fig. 7a there are given the noise contours at N.N.I. equal to 40 for different examined configurations and different paths, all of them belong to the same vertical plane and relative to a same movement way.

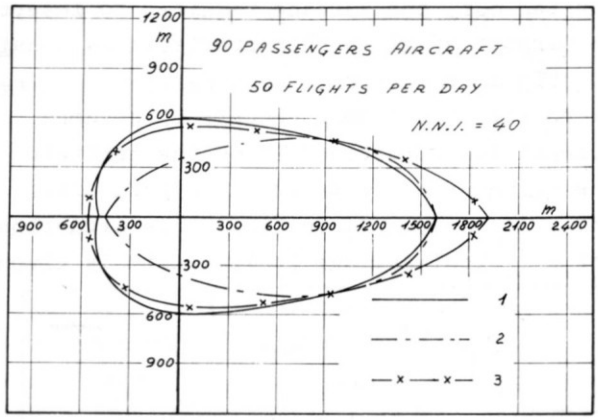


Fig. 7a - Contours for different T.O. profiles. 1.STOL T.O. with straight climb out. 2.LIFT FAN T.O. with 15m. vertical rise. 3.TILT WING vertical rise.

The plots have been calculated using data of the above mentioned study [4] and are relative to a technology progress extrapolated at 1970.

In Fig. 7b the same plots are given for a value of N.N.I. index equal to 60.

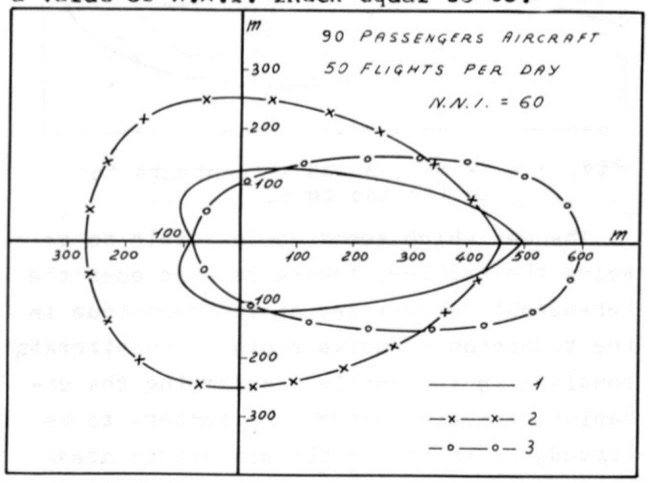


Fig. 7b - Contours for different T.O. profiles. 1.STOL T.O. with straight climb out. 2. TILT WING vertical flight. 3. LIFT FAN T.O. with 15m. vertical rise.

The areas interested by the noise are so quite reduced in comparison to the precedent case; of course the represented areas are relative to take-off and landing only in one way, if landing and take-off are towards different directions and in both the ways, as imposed by meteorological necessities, the figures are more complicated as the figures closed plot moves its ascis with the path plane; so in this case the area interested by the noise is considerably larger. As a result of the analysis carried out, the surface required to insert an airport of given characteristic is considerable if the surrounding district is a residential or economic center; it assumes acceptable proportions if on the contrary the surrounding district is an industrial one. As an example in Fig. 8 the situation for a typical average Italian city is given.

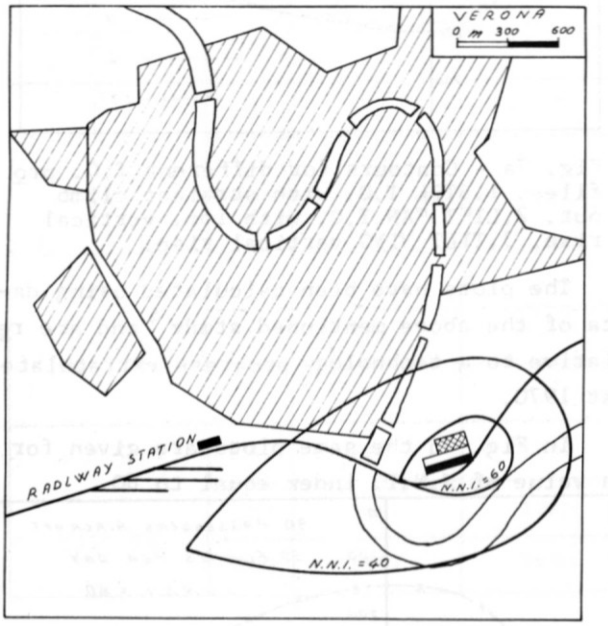


Fig. 8 - Example of noise contours for an Italian town.

The way which seems now possible to resolve the problem, taking into account the foreseeable progresses of the technique in the reduction of noise produced by aircraft, consists in rationally programming the urbanistic development of the centers to be served, by inserting the airport in areas which can tolerate the noise and which are as near as possible to the residential and economic centers and with which they are efficiently connected.

Research work which is intended to discover the limits of tolerability of the noise for the different categories of urban areas and to make the noise produced by aircraft more tolerable by operating on the propulsion systems or on the techniques of take-off and landing seems to be of decisive importance for a practical solution to this urgent problem. Solutions of this type would, if studied at the right time, consent to resolve the problem in a satisfactory manner for the most part of the Italian cities which in the next 10 years are destined to have a considerable urbanistic and industrial development of the areas which are still free.

For some larger centers, now already considerably developed and densely populated the problem may be more complex because of the already notable distances between the city center and the zones of future urbanistic development, which are potentially utilizable for the insertion of the airports, however in almost all the cases of such centers there exist industrial zones which are large enough and within which it should be possible to find areas of the necessary dimensions even inside the present urbanistic texture. In the above mentioned centers above all it will be indispensable to have also efficient connections with surface means between the airports and the many zones of origin of the traffic, which are present in large urban centers.

II.D - The operative capacity of the system and its interconnection with the problem of the airport.

One problem which must still be rationally resolved, to reach an efficient air transport system over short hauls, consists in guaranteeing a very high operative efficiency to the system itself, comparable to that of the systems of surface transport. The above mentioned efficiency is essentially tied to the minimum values of visibility and to the maximum values of atmospheric turbulence in correspondence to which the system can operate in conditions of safety.

The aircraft STOL and VTOL thanks to the low approaching speed will be able to opera te with lower minimums of velocity than tho se now consented to conventional aircraft (Figs 9a, 9b)[6] utilizing for the phases of instrumental and at sight flight infrastruc tures of performances not different from those employed for the above mentioned con ventional aircraft. The above mentioned characteristic of low speed should guarantee, with reference to the results of a pre liminary analysis of the national meteorolo gical situation, the level of operative efficiency requested in almost all the centers served already at the present state of the technique in the field of the infrastructures for the help from ground to flight.

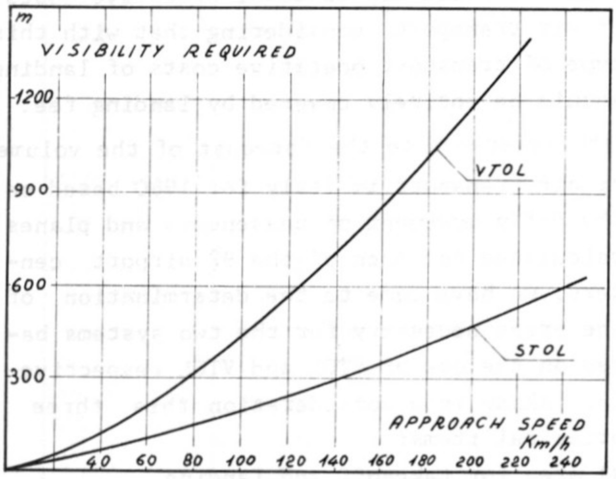


Fig. 9a - Slant range visibility required for VTOL and STOL operations.

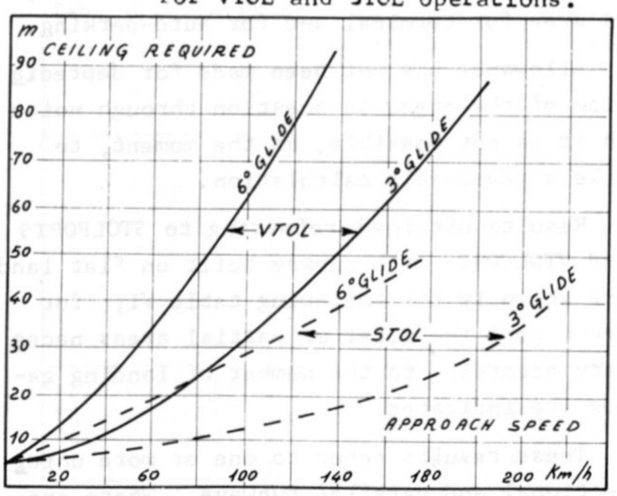


Fig. 9b - Ceiling required for VTOL and STOL approaches for two glide angles.

There exist however zones of northern Italy where because of the presence of very intense fogs for a large part of the year which practically reduce visibility to zero, the installation of advanced equipment both on the ground and on the aeroplane to be used for landings with visibility at zero or means of dispersing the fog, with propane or hot gases, already experimented successfully for conventional airports.[7] The cost of the application of these systems should be notably less for the airports with STOL and VTOL aircraft than for conventional airports because of the limited dimensions of the runways of the former: the application of no-visibility landing systems to the aeroplanes STOL and VTOL should assure a substan tial major safety than the same expenses for the applications to the conventional aircraft would give. The necessity of operating with very low minimums of visibility, as we have already noted, leads to flying during landing with low slope trajectories with a consequent increase in the area disturbed by the noise even if the fog formation bring about an increase in the attenuation of the noise with distance. It is therefore important to have adequate information of statistical character about the meteorological situation to be able to evaluate the effects of the noise and to make the best choice of the two solutions, above mentioned, to help in landings in conditions of scarce visibility.

It is equally important to establish the maximum of side wind which can be tolerated in the phases of slow flight of the planes STOL and VTOL. The possibility of operating in the above mentioned flight phases with si de winds of the highest possible intensity consenting the landing and take-off with tra jectories which still belong to a prefixed vertical plane, gives evident advantages in the solution of the problems which derive from the noise and in the dimensions of the necessary infrastructures. The problem ap pears notably different depending on which types of aircraft VTOL and STOL are conside red.

The methods now known of the research work in course in this direction are still too fragmentary to deduce definitive conclusions. From these results it seems however that some types of STOL aircraft can operate even in the presence of very intense side winds; for example with the MC 180 - Bg 941 it has been possible to make landings without difficulty with a side speed of the wind of 32 km/h.[4]

Therefore even if the notable quantity of research work is indispensable to arrive at designs of STOL aircraft which make it possible to obtain an adequate flight quality in the phases of slow fhight with strong side winds, it seems reasonable to retain possible the obtaining elevated operative efficiencies with operations of unidirectional take-off and landing.

It seems therefore very important to have exact statistical data about the intensity and direction of the winds during the year for each locality where the possibility of building an airport is prospected. These data will make it possible to establish if the construction of a unidirectional STOL-VTOLPORT is possible, in view of the notable economic advantages connected with this solution and will consent the establishing of the best direction of the runway.

The possibility of reaching a good operative efficiency, in addition to a rational choice of the site of the airport and of the infrastructures for take-off and landing, depends essentially on the availability of STOL and VTOL aircraft with adequate aeromechanical characteristics in the slow flight phases.

The results, which are known at the present, obtained by a research work carried out in this direction have confirmed the operative reliability of numerous STOL and VTOL philosophies. However further researches for reaching solutions optimized in relation to the whole economy of the system of air transport, are still necessary.

Finally it is urgent to resolve the problem of the central control of air traffic both near the aiport and cruising utilizing a given central system able to minimize costs and to augment the system safety.

II.E - Economic evaluation of airfields and the relative infrastructures.

The introduction of airports into the urban network of the centers to be served is not only a problem of noise, of prevailing weather conditions in the airfield area and of the possibilities of easy transportation between the airport itself and various centers where there is the source of traffic, but it is also a problem of economy.

This Office has intended to study a basic system of costing of airports and their relationship to total operative costs of air transport, considering that with this type of transport operative costs of landing should be entirely covered by landing fee. With reference to the forecast of the volume of air transport in Italy for 1980 based on the daily movement of passengers and planes calculated for each of the 92 airport centers, we have come to the determination of the areas necessary for the two systems based on the use of STOL and VTOL respectively, taking into consideration this three principal items:

a) area for take-off and landing
b) area for parking, taxiing and servicing
c) area for terminal and for auto-parking.

Allowance has not been made for depreciation of the areas in question through noise as it is not possible, at the moment, to make a reasonable calculation.

Results obtained referring to STOLPORTS and VTOLPORTS with runway built on flat land are shown in the following table VI; for every port the total or partial areas necessary according to the number of landing gates are indicated.

These results refer to one or more unidirectional and parallel runways. Where prevailing weather conditions make two runways at 90 degrees necessary the area necessary

NUMBER OF GATES		2	4	6	8	12	14	16
TAKE OFF AND LANDING AREA (m^2)	STOL	9000	9000	9000	9000	18000	18000	18000
	VTOL	7200	7200	7200	7200	14400	14400	14400
APRON TAXIWAY (m^2)	STOL	19500	23500	28500	45100	64800	72900	89000
	VTOL	11000	20000	29000	44500	64800	72900	89000
TERMINAL (m^2)	STOL	3000	4800	7500	10200	11000	12150	15000
	VTOL	3000	4800	7500	10200	11000	12150	15000
PARKING (m^2)	STOL	6000	9600	16200	24000	25800	28800	60000
	VTOL	6000	9600	16200	24000	25800	28800	60000
TOTAL AREA (m^2)	STOL	37500	43900	61200	88300	119600	131850	182000
	VTOL	27200	41600	69900	85900	116000	128250	178400

Tab. VI - Number of aircraft for short-haul transportation in 1980.

GATE N°		2	4	6	8	12	14	16
AIRPORT N°		43	21	15	8	2	1	2
MEAN NUMBER OF PASS. IN A DAY		1500	3000	6000	9000	11000	15000	25000
MEAN NUMBER OF PASSENGER IN A DAY	STOL	41500	53100	66500	94000	115000	127000	182000
	VTOL	32200	47800	65700	91900	111000	123000	178000
INVESTMENT COST PER AIRPORT (MillionLit)	STOL	1194,8	1820,7	3033,6	4030	5312,4	5813,5	7274
	VTOL	1163,1	1817,9	3041,1	4056,5	5311,4	5768,5	7266
YEARLY OPERATING COST (Million of Lit)	STOL	215,28	328,07	547,36	735,8	956,24	1057,35	13194
	VTOL	209,51	327,19	546,11	729,65	955,14	1036,85	1308,6

Tab. VII - Airport area costs and passengers summary.

GATE NUMBER		2	4	6	8	12	14	16
AREA	STOL	1,7 %	2,31 %	9,9 %	10,8 %	18 %	18,1 %	20 %
	VTOL	1,6 %	2,25 %	9,8 %	10,5 %	17,5 %	17,7 %	19,6 %
TERMINAL	STOL	63 %	65,9 %	62 %	62,6 %	51,7 %	51,9 %	51,5 %
	VTOL	64,5 %	66 %	61,9 %	63 %	51,5 %	52,7 %	51,5 %
ELECTRONIC INFRASTRUCTURES AND EQUIPMENTS	STOL	25,4 %	22,5 %	21 %	18,9 %	22,1 %	22,5 %	19,8 %
	VTOL	24 %	22,5 %	21 %	18,9 %	22,1 %	22,6 %	19,8 %

Tab. VIII - Airport investment costs summary.

is increased by about 25%.

It can be noted that there is not much difference in airport areas necessary for the two systems STOL and VTOL, in fact the incidence of the area for the runways on the total area of the STOL-VTOLPORT is quite small (11% and 14% for VTOL and STOL respectively).

In the tables VII and VIII are shown the characteristics and the costs of each airport and the total investments and the percentages of the various cost items for the 92 Italian airports in the suggested air network; the costs of the radioelectric insfrastructure have been calculated after the results of a study of MIT.[8]

The difference in the costs of total infrastructure for the two systems STOL and VTOL is negligible because, as previously noted, the characteristics of the airplane has little effect on the size of the airport. Costs of VTOLPORTS have been founf to be much lower that those of STOLPORTS by researchers[9] who have allowed for airports with elevated runways, parking and service areas, with terminals and autoparks underneath; such ports with three storeys have been considered more suitable for densely populated centers on the east cost of the USA. This solution is generally more costly than that of one storey, with runways on the ground as for as the Italian situation is concerned; in a second more detailed estimate, the elevated systems, as mentioned, might be convenient in certain Italian centers that are very extended and densely populated and where the cost of the area is well above the national average.

The table VII also shows the results of a valuation of annual operational costs of a port, on which has been based the landing fee, following the plan already announced.

II.F - Economic evaluation of air transport for short haul and comparison between STOL and VTOL systems.

It is noted that operative costs are the sum of direct operative costs (already estimated for the three items in paragraph II), of the landing fees, calculated in paragraph II and also the indirect operative costs.

The latter is made up as follows:

a) Costs of passengers
b) Port costs
c) Sales cost and service development
d) General administration cost.

This depends largely on the method of managing the transport system; its burden on the total cost however is certainly diminishing continuously, not only because of increasing productivity of the personnel and equipment but also because of the improvement in management.

The business organization of the planned system of air transport for short hauls could certainly use the operative experience gathered from the running of conventional air transport systems.

Certain cost items such as a) and c) can be considerably controlled by offering the short haul passenger service reduced to the essentials, saving in personnel, well organized ticket sales making full use of automatic ticket machines.

On the basis of previous examination as indirect operative costs do not depend on the type of plane but on the kind of service offered, it is considered to be sufficient to base on the trends of the operative costs of European and American airlanes working on medium and short hauls. That has brought an evaluation of 4 Lit/seat-km for the indirect operating cost for the planned system of short haul air transport.

On the basis of such evaluation the total operating costs appearing in Figs. 10a and 10b have been calculated. In the tables IX and X we show total average operating cost on a distribution of passenger/km for the length of the journey, and the percentage of burden of the various items on the total cost. From an examination of the data given in the tables, the following can be deduced:

a) cost of short haul air transport calculated to 1980 would be lower than existing

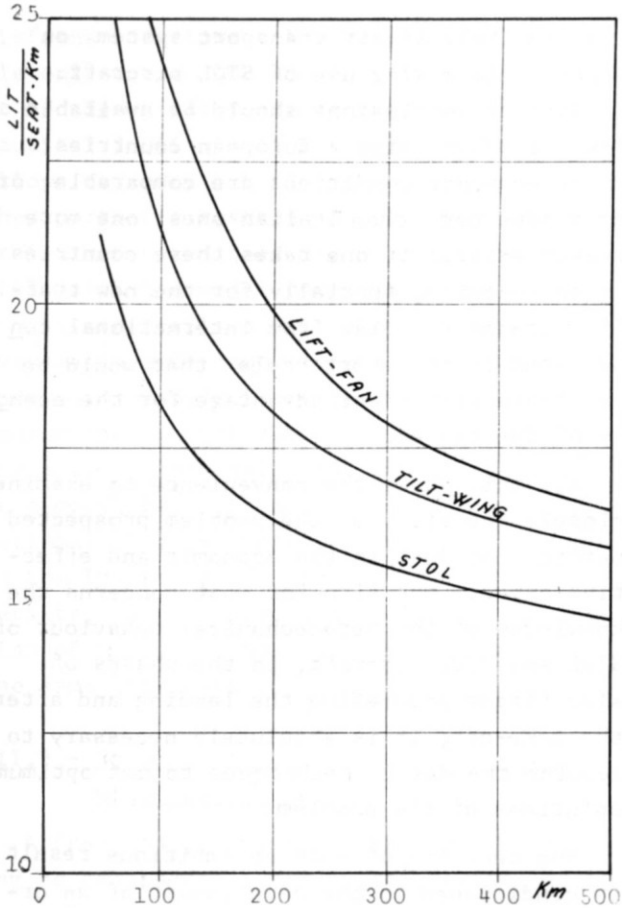


Fig. 10a - Total operating costs - 40 seats aircraft.

conventional airlines'

b) the progressive reduction of conventional airline costs will be determined by a foreseen increase in traffic notably less than the traffic that the new systems of short haul air transport, it is thought can handle owing to the greater demand

c) in conclusion the result of greater in-

AIRCRAFT		STOL	TILT WING	LIFT FAN
40 SEATS AIRCRAFT L.F. 60%	Lit / Seat·Km	15,62	18	19,5
	Lit / Pass.·Km	26,1	30	32,5
90 SEATS AIRCRAFT L.F. 70%	Lit / Seat·Km	14,57	16,6	17,55
	Lit / Pass.·Km	20,85	23,7	25,1
TOTAL OPERATIONS L.F. 65%	Lit / Seat·Km	15,3	17,6	18,93
	Lit / Pass.·Km	24,3	27,9	30

Tab. IX - Mean cost of seat Km and pass.Km.

AIRCRAFT		STOL	TILT-WING	LIFT-FAN
D.O.C.		8,77	11,1	12,43
		57,3 %	63 %	66,7 %
LANDING FEE		2,53	2,5	2,5
		16,5 %	14,2 %	14,2 %
I.O.C.		4	4	4
		26,2 %	22,8 %	21,1 %
T.O.C.		15,3	17,6	18,93
		100 %	100 %	100 %

Tab. X - Total operating costs summary.

crease of traffic caused by a specially studied system of air transport for short hauls would prevail over the effect of the higher costs of operating STOL and VTOL planes

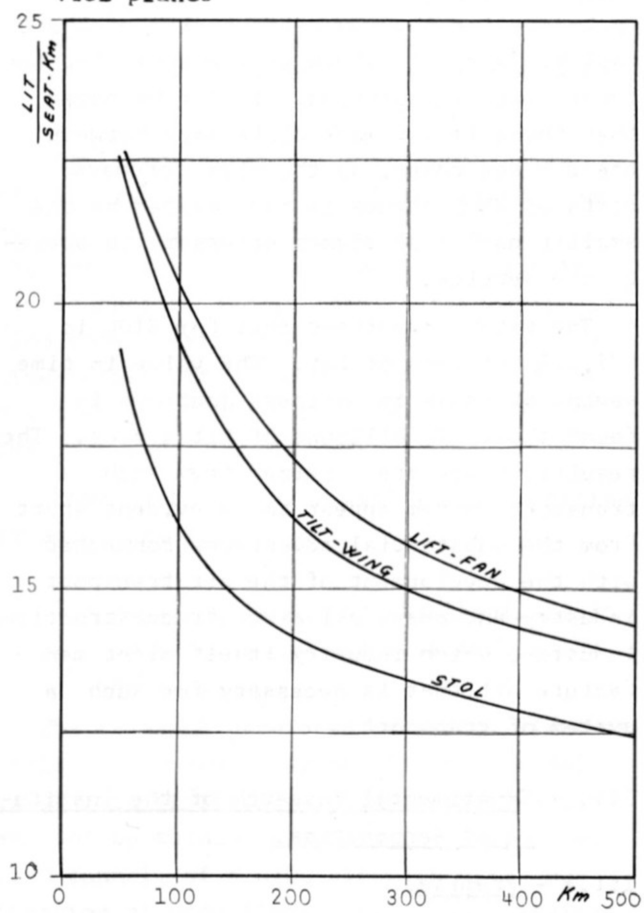


Fig. 10b - Total operating costs - 90 seats aircraft.

d) as far as the three types of planes are concerned, STOL is clearly more economic followed by VTOL-TILT-WING and last VTOL LIFT-FAN.

This last conclusion is drawn from the fact that port operating costs and tax for landing pass on the assumption of airport configuration are practically the same for the three systems and as far as STOL is concerned it is the most economical because of its low direct operating costs.

The system VTOL-TILT-WING appears suitable only where it is generally necessary to use three-storey VTOLPORTS; this would only be convenient when the cost of the areas of the centers served is very high. It is not considered that this would happen in the near future in Europe where the conditions mentioned would prevail only in a small number of important centers and not in the majority of urban centers served.

A calculation of the investments necessary to realize the suggested system of short haul transport is shown in the table for the three cases in question. It can be noted that there is not much difference between these three cases, as the high purchase costs of VTOL planes is compensated by the smaller number of planes necessary to operate the service.

The total investment cost for STOL is 677,125 billions of Lit. The value in time saving of those in business journeys is found about 270 billions of Lit a year. The results, therefore obtained from such a transport system appear to be evident apart from the substantial advantages connected with the development of the air transport industry and above all aircraft construction industry, which industry itself might manufacture all that is necessary for such a system of transport.

III. - Experimental research of the Institute of Aeronautics.

III.A - Premise.

The economic study done before has shown the possibility and the convenience to develop in Italy an air transport system on short hauls making use of STOL aircraft.

Similar conclusions should be available for the other single European countries, whose economic conditions are comparable, or more advanced than Italian ones; one more reason exists: if one takes these countries as an assembly, specially for the new traffic streams deriving from international connections in the short hauls that would be available with great advantage for the economy of the system.

All this shows the convenience to examine closely the study of the problem prospected before, not just in the economic and effective aspect, but also for what concerns the knowledge of the aeromechanical behaviour of STOL and VTOL aircraft, in the phases of slow flight preceeding the landing and after the take-off; it is absolutely necessary to develop the design techniques to get optimum solutions of the problem.

The reaching of such an ambitious result is conditioned to the development of an organic program of cooperative and coordinate research between the Research Institutes and industries in a desirable european dimension; that research only would be able to face and to develop such a serious subject with a good probability of obtaining positive economic results.

In this prospect the Aeronautical Institute of Pisa University has started a research simultaneously to the technical-economic one , intentioned to develop a construction and experimentation methodology on powered and servocontrolled free flying models with dynamic similarity of STOL and VTOL aircraft, to study the complex aeromechanical phenomena which characterize the named aircraft in the slow flight phases.[10]

Experiences on flying models were already carried out successfully in other countries, particulary in U.S.A., nevertheless in Italy it appears to be necessary to develop a methodology taking into account plants now existing or available in the near future in this country, to obtain technically satisfying solutions. Now in Italy is available only one of the above mentioned plants: it is the whirling arm facility of the Aeronautical Institute of Milan Politechnic; it allows to carry out flying model tests either partially restrained, with the "Control-Line" technique, or, within certain limits, with the model completely free (these limits are realized with electric cables and eventually with compressed air ducts, necessary for boundary layer control and as power source for control surfaces. In the future a low speed aerodynamic wind tunnel fit for free model tests should be available; the building of this tunnel, entirely designed in the Institute of Aeronautics of Pisa University, is estimated with priority in the plan of building and scientific powering of the same University.

III.B - Some considerations on the flying model techniques.

A free model flying in dynamic similarity may be considered a mechanical device for integrating the differential equations of the motion of an aircraft of which the model itself, made in a proper scale, is able to reproduce all the geometric,inertial, aerodynamic and power characteristics.

The reliability of the information that can be obtained with such a technique, depends on the difficulties connected with the fullfilment of a dynamic and aerodynamic similarity. The firt of these difficulties can be overcome by refining adequately the technique of the model costruction. On the contrary the second can't be overcome conveniently, because of the unavoidable differences between the Reynold number of the model and the one of the aircraft. This last condition gives an unquestionable limit to the value of the results one may achieve with the named technique; however, as it has been shown in tests made in U.S.A.[11], the effect caused by Reynold number, can be minimized if the flight conditions are under the critical incidence, provide the dimensions of the model are not reduced too much (the wing main chord can't be smaller than 30cms). If the flight conditions are over the critical incidence, the model will act in a different way; however the results that can be obtained in these tests are still meaningful because the stall begins in the two cases at different incidences but with similar characteristics; so that the study of the aeromechanical behaviour of the model in the test flight conditions, gives information still valid for the understanding of the aeromechanic behaviour of the aircraft in this flight phase.

Another condition that brings experimental difficulties is the one of the angular motions, that are faster in the model, because of dynamic similarity; that brings piloting troubles with the presence of oscillatory motions, whose minimum admissible period is connected to the reflexes of human pilots. Because of the named times and because of the lack of accelerometric and muscolar spurs, the model piloting is quite different from the one corresponding to the aircraft, so that the judgements given by the pilots about the handling characteristics, must be taken just as indications.

The flight model tests in aerodynamic similarity, even with the limitations named before, are able to obtain information on the aeromechanical behaviour of a certain configuration; and if this configuration is also conveniently tested in the aerodynamic wind-tunnel, it is possible to establish a convenient basis for a correct start of the STOL and VTOL aircraft design.

Other methodologies will result certainly more expensive.

III.C - Activity of the Aeronautical Institute of Pisa University for flying models.

The research developed until now, in this sector is based essentially on a model in dynamic similarity design, construction and set up through tests in the aerodynamic wind-tunnel, of a STOL aircraft with deflection of propellers slip stream obtained with triple slotted flaps in the imboard side of the wing, and with a plain flap with boundary layer control in outboard side. The external flaps also have a differential motion for the rolling control. The realization of this first model whose final assembly is achieving, was very laborious, because it has required the set up of a particulary delicate constructive technique apt to solve the problems connected to obtain the similarity; this is very difficult because of the wight restricted limits and because of the very limited allowances that must be regarded in several parts of the model, specially as regards the propellers, the moving surfaces on the leading and trailing edge of the wing and the tail, and the complex kinematic devices utilized for their motion.

As regards the model and particularly the aerodynamic surfaces construction, an equipment principally based on the bonding under pressure and heating technique, was designed and set up. This technique allows to obtain the required high accuracy and a remarkable gain in weight. It has required quite a long time to set up the named constructive methodology; but very satisfactory results have been obtained, so that these constructive methods can be used for the construction of new models in a relative short time.

Besides one equipment for propellers production has been designed, constructed and set up. This equipment has made possible the overcoming of very difficult problems connected with the restricted tolerances derived from the dynamic similarity. This methodology too will be able to be applied successfully later on.

The set up tests were done with a half-wing, constructed with the named technique, filled up with all the devices required for the flying tests made in the small aerodynamic wing-tunnel of the Aeronautical Institute of Pisa University; for this purpose the reflection plate technique has been used, together with a three components extensimetric wind-tunnel balance, designed and constructed for this purpose.[10 12]

These tests were performed in the following way:

1 - Boundary layer control set up, and optimum values determination for the jet coefficient, for some typical wing configurations.
2 - Four propellers motion gearing set up.
3 - Slip stream deflection of the half-wing characteristics determinations.
4 - Optimum setting of the propellers center line.
5 - Experimental comparative studies of some types of nacelles, related to the wing-nacelles interference problem.
6 - Aerodynamic characteristics determination of a half-wing with boundary layer control, and with propellers working at different steady conditions.
7 - Control system set up, obtained with an expressly prepared test bed and successive tests in the wind-tunnel to simulate entirely the flight conditions.

Conclusions

A research about the use of STOL and VTOL aircraft in civil air transport is beeing carried out by the Institute of Aeronautics of Pisa University with financial contribution of C.N.R. This research is developed towards the following two directions:

a) Technical-economic evaluation of a short haul air transport system based on the use of STOL and VTOL planes which should become operative in Europe in 1980.
b) Experimental research about the aeromechanical behaviour of STOL and VTOL aircraft in the slow flight phases by the use of flying models in dynamic similarity.

In the present work as regards the item

a) it was dealt with the basic problems to be faced to reach an efficient short haul transport integrated system, essentially employing STOL and VTOL planes. Results of a preliminary economic evaluation of a short haul air transport system operating in 1980 in Italy were exposed.

Some results about research b) were also exhibited; this research attempts to set up a methodology fit for the study of the aero mechanical phenomena in STOL and VTOL planes by the aid of flying models in dynamic similarity and the use of the existing in Italy.

References

1) Lazzarino L. - Trasporti aerei civili sul le medie tratte con velivoli STOL nel quadro di una politica generale di programmazione dei trasporti pub blici. Simposio sugli studi di Tecnica ed Economia dei Trasporti. Bres sanone 1966.

2) Bacci M. - La dinamica demografica delle regioni italiane. Edizioni Giuffré. Roma.

3) E.N.I.T. - Previsioni sul reddito per di versi paesi europei. Centro di docu mentazione. 1967.

4) Mc Donnel A.C. - Technical and economical evaluation of aircraft for intercity short-haul transportation. F.A.A. ADS-74. 1 - 1966.

5) Committee on the problem of Noise - Final Report - Her Majesty's STATIONERY OFFICE - London 1966.

6) Reeder J.P. - The impact of V/STOL aircraft on instrument weather operations. AGARD Report 485.

7) Società Esercizi Aeroportuali di Milano. Relazioni e Bilancio, Milano 1964.

8) M.I.T. - A system analysis of short haul air transportation - PB - 169-521 - 1965.

9) Vertical Lift Aircraft Council of A.I.A. The Economics of VTOL Systems.1966.

10) Salvetti A. - Ricerche su velivoli da trasporto per passeggeri e posta a decollo ed atterramento raccorciati. Rivista Aeronautica. 1965.

11) Campbell J.P. AGARDograph 76 - 1963.

12) Rossoni G., Del Puglia A. - Risultati preliminari di prove alla galleria aerodinamica su di un modello di velivolo STOL. Aerotecnica, Aprile 1967.

13) Kryter K.D. - J. Acoust. Soc. Amer.,31 1415 (1959).