REGIONAL AIR TRANSPORT IN EUROPE: THE POTENTIAL ROLE OF THE CIVIL TILTROTOR IN REDUCING AIRSIDE CONGESTION

Vincenzo Correnti
University of Palermo
Palermo, Sicily, Italy

Matteo Ignaccolo
University of Catania

Salvatore Caprì
University of Catania

Giuseppe Inturri
University of Catania
Catania, Sicily, Italy

ABSTRACT

The volume of air traffic worldwide is still in constant growth despite unfair events that sometimes occur. The demand for regional air transport is also increasing, thanks in part to the use of new vehicles purposely designed for short range flights which make this means of transport more attractive than in the past. This paper studies the possibility of using aircraft capable of vertical or short takeoff or landing (V/STOL), in particular the tiltrotor, in the regional air transport market and the impact on airport capacity that the use of this craft would have. With this in mind the advantages and disadvantages of using this vehicle are identified, as well as the changes to be made to the air transport system in order to exploit its full potential.

Vincenzo Correnti is full professor of Transportation Technique and Economics at the University of Palermo. He is author of more than 70 scientific volumes and monographs concerning Transport Engineering and Economics. From 1980 to 1989 he was at the head of the Transportation Finalized Project of the Italian National Research Council.
Matteo Ignaccolo is an associate professor at the University of Catania. He has taught Transport Technique and Economics since 1993. His research covers most transport topics, with special attention to planning and management of air transport systems.

INTRODUCTION

Recent air traffic developments have shown a consistent increase in the volume of traffic handled by regional airports. The growth in regional airport traffic has been considerably furthered by an increase in inter-European connections and flight frequency, boosted by an increase in point-to-point passenger transport between the most important European cities and, therefore, more flights feeding the European hubs. This new phenomenon does not question the role of these hubs, but does open interesting perspectives. It is, in fact, in a country's interest to support growth in European and domestic point-to-point traffic, develop its potential for capturing tourist traffic and favor conditions that avoid a loss of traffic to competing hubs.

The regional airline sector today is one of the most dynamic. More than 300 million passengers from around the world crowded regional aircraft during the last year. This was due to various strategies adopted by regional companies in order to become more integrated and to a change in their operational networks in an effort to define and maintain their role within the current movement towards liberalization and globalization (Graham, 1997).

An element emerging from an analysis of regional air transport developments is that the increase in flights has considerably increased the problem of airport congestion to levels almost reaching saturation point and, as a consequence, has overloaded the air traffic control (ATC) system taking it to the limit of its operational capacity and safety limits. The consequence is that airports are no longer able to handle all the converging flights, producing frequent delays which result in the airport losing its main characteristic: speed of transfer.

The use of aircraft capable of vertical take-offs and landings (VTOL) and/or capable of short take-offs and landings (STOL) offers one possible way of making the situation less critical. An aircraft capable of vertical and short take-offs and landings (V/STOL) is a category of aircraft to which the helicopter traditionally belongs and, more recently, the tiltrotor. This latter is between rotating wing and fixed wing craft (i.e., between the helicopter and the traditional airplane). It was developed for military use and is now being developed for the civilian transport market.

Salvatore Caprì obtained a Ph.D. degree in Transportation Technique and Economics in 2002 at the University of Palermo. His main research fields are air transport management and urban transport systems.

Giuseppe Inturri has a Ph.D. in Transportation Technique and Economics and assistant professor at the University of Catania. He teaches Transport Planning and his main research fields are airport planning, revenue management and transit systems.

In this context, regional air traffic transport operating with rotating wing craft can be inserted into the wider transport system offering, prevalently, a supplementary rapid link service for specific types of connection. If it is true that there is a certain diversion from other means of transport towards air transport, this is certainly, to a considerable degree, due to the time saved in connections and a reduction in delays.

V/STOL can use different flight procedures from fixed-wing craft. Exploiting the maximum flight potential of these machines, it would be possible to achieve a very evident reduction in approach, landing, take-off, and departure times. Benefits could come from an operative use of the tiltrotor passenger craft by increasing the number of operations per hour in the airports and deviating part of their traffic towards this aircraft—especially for minor routes—thereby freeing some slots that could be used for larger aircraft with a greater operating range. On the other hand, with suitable procedures, inter-regional connections could be increased to and from the large hubs departing from *vertiports* more widely distributed over the territory and therefore able to ensure a better integration in a territorial context.

In addition, airport congestion is not only limited by runway capacity. Sometimes it is also limited by inadequate access by ground transportation systems. A V/STOL feeder line could improve the system. Despite several helicopter services at some airports, which have not been so successful, the world in 2030 will be even more congested and complex and V/STOL could be part of an integrated transport concept (Schmitt, 2001).

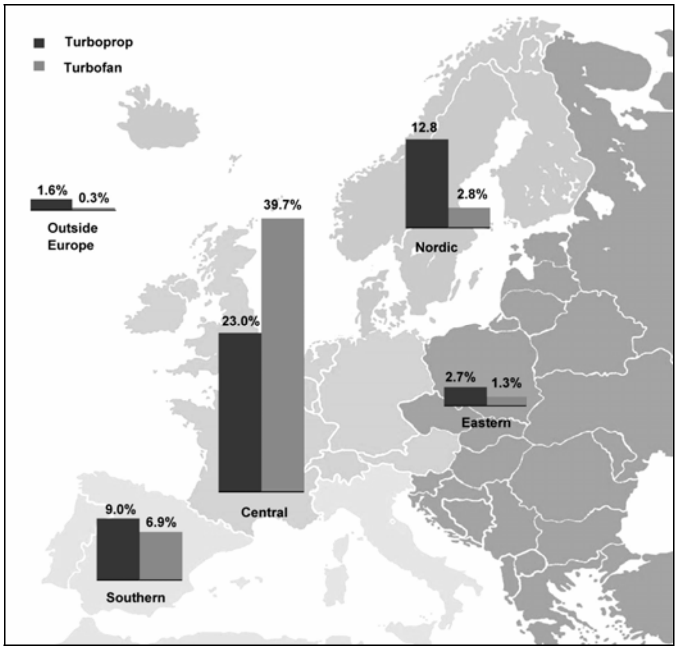
REGIONAL AIR TRANSPORT IN EUROPE

The business of regional air companies is a continuously developing phenomenon, strengthened by the events in past years and encouraged by forecasts of ever increasing traffic. A possible scenario for regional air transport in the near future is greatly influenced by the fact that airports have now reached their capacity limit and problems created by noise and atmospheric pollution are obliging the aeronautical industry to make precise choices when buying aircraft.

The forecasts of both air companies and airplane producers tend towards a choice of larger models than before (e.g., the almost complete abandoning of the 50 seat models for the 70 seat ones). The perspective of regional aircraft manufacturers is that of producing a family of aircraft that offer operational and cost flexibility with maintenance and running aimed at simplicity and savings.

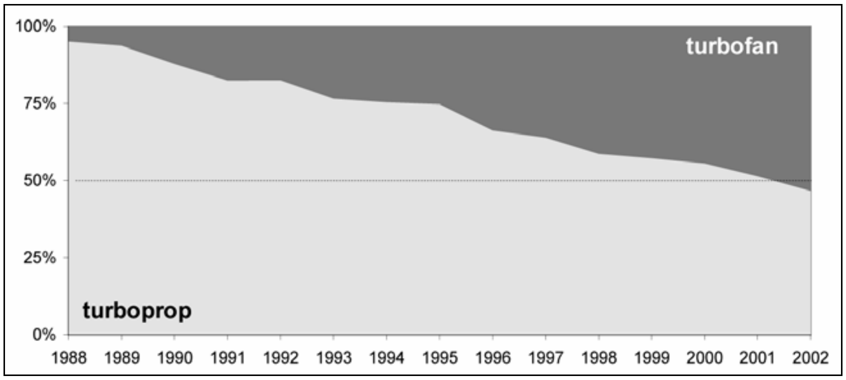
In the European regional air transport market there is still a lot of confusion and many differences between the various airlines. One area of confusion is the total variety of aircraft that fill the skies and airports. This non-uniformity of the fleet leads to an inevitable increase in costs both for maintenance and crew training. Figure 1 shows the geographical distribution of two large families of aircraft—turbojet and turboprop—in European regional areas.

Figure 1. Fleet distribution of European regional airlines, by region, 2002



Source: (ERA, 2002)

Figure 2. Passenger fleet, turboprop and turbofan split for European regional airlines, 2002



Source: (ERA, 2002)

Figure 2 shows the trend of regional transport fleet distribution according to propulsion type (turbofan and turboprop). It shows an increase in jets compared to turboprops. This is the case especially in aircrafts seating from 40 to 70. Over the years, a reduction in the number of large turboprops (40-60 seats) has also been seen, replaced by the turbojet with the same capacity but offering better performance and having more advanced technology, that better meets the needs of the market, and also receives a positive reaction from its users, due to the greater comfort they offer.

From sales forecasts and orders placed by the main aeronautical industries it is possible to define even further the near future scenario for regional air transport. The manufacturing industries agree that aircraft with 20-39 seats will increase by 12%, while about 45% of the total will be represented by aircraft with 40-59 seats; 33% represented by aircraft with 60-79 seats, while the remaining 10% made up of planes with 80-99 seats (Bombardier, 2001).

The airline fleets undertaking regional transport will, therefore, undergo substantial modifications. Forecasts show that almost 50% of the world market will be represented in the near future by planes with 50 seats, those with 70 seats will constitute 31% of the total, while those with 30 seats will decrease from the present 38% to 12%. The number of craft with 70 seats or more will, instead, almost double going from today's 7% to 13% in the next few years (ERA, 2002).

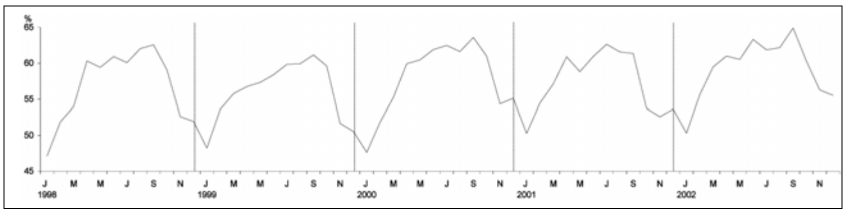
The main pointers for establishing the state of health of European airlines, especially those offering regional transport services, can be deduced from the following graphs and tables that summarize the fundamental factors for the characterization of air transport. The data that follow are from

European Regions Airline Association sources and refer to 2002 and the beginning of 2003.

It can be seen that in the last period examined (2002 – first quarter 2003) the increase in regional passenger traffic underwent a slight drop, which according to the experts can be attributed to the war in Iraq, but nevertheless constituted about 7-8% monthly. This is controversial data that, on the one hand provides an incentive for companies to develop this sector but on the other reinforces worries regarding an imminent collapse of the air transport system due to airport congestion.

Figure 3 illustrates the trend of the load factor of aircraft, which is defined as the ratio between the number of passengers and the available capacity, and represents another important parameter for evaluating both airlines and aircraft manufacturing companies. It shows how there have not been significant increases, except for the seasonal ones, in the load factor value in the last years.

Figure 3. Passenger load factor growth for European regional airlines, 1998-2002.



Source: (ERA, 2002)

From an evaluation of all these factors it emerges that aircraft fleets have adapted in order to respond better to market needs, in which the new aircraft models must satisfy the variability of all these features.

From an observation of the collected data it can be deduced that turboprop models continue to lose favor with both the airlines who should buy them and the manufacturers, who view turbofan models more favorably. One of the causes for this change in strategy on the part of the producers is that, besides having higher operating speeds and consequently shorter connection times, they also offer greater comfort to passengers.

THE TILTROTOR AND ITS FEATURES

Overview

After more than twenty years of research and development the craft known as the tiltrotor—in particular model BA609 produced by Agusta, capable of combining the speed and autonomy of a turboprop and having the capacity to land and take-off in the same way as a helicopter—is now on the point of becoming a reality in the field of commercial transport services. This is proved by the fact that the first model ever realized for the commercial sector will be on the market in the near future and also by the interest demonstrated by research organizations [Ames Research Center, National Aeronautics and Space Administration (NASA)] and manufacturers (Eurocopter, Bell, Sikorsky) for the development of this kind of aircraft. A study carried out on behalf of the United States Department of Transportation (US DOT, 1995) concluded that a new kind of civilian transport system based on tiltrotors would be possible in the medium term and that a craft carrying from 10 to 40 passengers was technically, economically and environmentally feasible.

At the same time, Sikorsky is actively developing the technology for the next generation of tiltrotors, based on engine gondolas having rotors of varying diameter created in order to reduce flight problems after conversion (excessive penalization of performance due to the large rotor disc). They all descend from one model, the XV-15, developed by NASA, the U.S. Army and Bell Helicopters Textron, Inc., together at the Ames Laboratory. Over the course of more than twenty years' research carried out on them, there is now a sufficiently large database to be able to develop two projects, the V-22 and the BA609.

As already mentioned, the tiltrotor has cruising capability typical of the modern turboprops (comfort, speed and autonomy) and a take-off/departure and landing/approach capability typical of rotating wing machines, consequently making ground operations in much more limited spaces possible, with less expensive, less complicated and less bulky infrastructures than those necessary for conventional aircraft (CTOL).

Structurally the tiltrotor is equipped with a special propelling apparatus (proptors). This is made up of two engine gondolas mounted in correspondence to the wing extremities capable of rotating entirely at an angle of more than ninety degrees. In this way not only is vertical take-off possible so is backward movement while in helicopter mode (HELO mode). Once vertical take-off has taken place, the rotation of the gondolas is the most critical phase of the craft's whole flight complexity, both for landing and take-off. In this phase the flight mode changes from being supported by the propulsive equipment to a normal cruising flight phase. The considerable workload to which pilots of the V-22 military transport aircraft are subject has made the creation of a commercial model deriving directly from them highly improbable. The same reasons dictated the choices of controls implemented in the BA609.

In general the tiltrotor, the natural evolution and union of fixed wing and rotating wing aircraft, is a machine characterized by the possibility of operating indifferently as a CTOL, STOL or VTOL aircraft according to the needs of the moment. A commercial tiltrotor could take off vertically and change to the typical flight conditions of a plane in less than thirty seconds, accelerate to a speed of more than 200 knots (like a jet) to fly to a height of more than 30,000 feet and, once cruising, fly at more than 300 knots for the whole stretch. On arrival, a steep descent at maximum speed can be hypothesized with the aid of navigation systems based on global positioning system (GPS) precision equipment, a rapid deceleration then a transfer to HELO mode to complete the final approach up to a vertical touch down using instrumental meteorological conditions navigation systems.

Compared to a conventional regional turboprop (for example the SAAB 340 or the DHC-8-100) the tiltrotor has a better turning range (3800/3900 feet at 60 knots compared to 7700/7800 feet at 120 knots) and steeper descent and ascent angles (more than 55° in ascent at a speed of 110/120 knots and 12/15° in descent at less than 45/90 knots against 12° and 3° at 65/120 knots).

The departure phase of the tiltrotor can be divided into 4 sub-phases:

1. Take-off;
2. Acceleration to ascent speed in HELO mode;
3. Change to aircraft (A/C) mode; and
4. Ascent and acceleration in A/C mode.

Once the critical decision point at about 55 feet has been overcome, the pilot from this point on begins vertical acceleration in order to take the aircraft to a height where he or she can start to vary the propeller configuration, rotating them and bringing them to the A/C flight mode position (i.e., similar to an airplane). For the tiltrotor to take off using this type of take-off procedure certain criteria should be followed. In fact, it is necessary to have (a) enough height to overcome any obstacles near the platform, and (b) in the case of failed take-off, the distance to the departure point must be about 600 feet.

Descent in A/C mode is very similar to that of a normal fixed-wing airplane with an angle depending mainly on traffic control and passenger comfort; to begin the change back to tiltrotor form, speed must be reduced to about 140 knots while the flaps must be positioned at about 30° and propeller speed must be increased from 80% to 100%. At the same time a sophisticated system instantly adjusts the propeller angle with variations of 2°, considerably helping the complicated maneuvers of the pilot.

The principal differences of a V/STOL from both a traditional plane and a helicopter are reported in Table 1, from which it can be particularly noted that the landing and take-off (LTO) distances are considerably less that those of normal fixed-wing craft, giving a high flexibility, above all, in areas near the airport where the final LTO operations take place.

Table 1. Characteristics of helicopter, tiltrotor and conventional aircraft

	Helicopter	Tiltrotor	Conventional Aircraft
Speed	-25 - +160 kts	-25 - +350 kts	+100 - +480 kts
Sideward Movement Capability	20 kts right and left		None
Maneuverability at Low Speed	Excellent		Extremely bad
Landing and Take-off Distance	0 – 600 ft.		3,000 – 10,000 ft.
Climb Path Angle	Up to 90°		Up to 15°
Approach Path Angle	Up to15° (STOL)	Up to 20° (STOL)	Up to 6°

Due to the tiltrotor's particular features, the development of the BA609 posed some fundamental objectives:

1. Reduce the pilot's workload. This objective is to allow the pilot to obtain the desired result from his or her controls by adopting both the control techniques that are peculiar to the tiltrotor and using conventional control techniques. This will simplify the transition of pilots coming from helicopters or planes;
2. Improve flight safety and reliability. From its conception the V/STOL has been endowed with an excess of controls and monitoring equipment with well-timed alarms that guarantee complete safety in the case of transitory phases due to faults and the automatic reconfiguration of the system;
3. Reduce costs and weight. This has been reached thanks to the use of the most advanced flight systems developed during simulations that reproduced high risk situations as faithfully as possible and comparisons made with results coming from flight trials of other crafts.

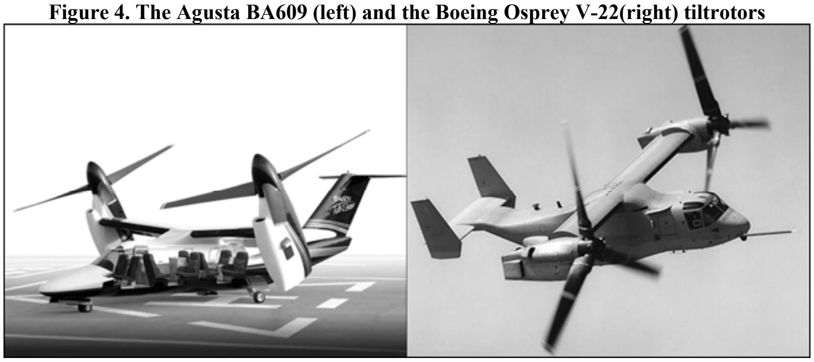
The two best-known tiltrotor models are the Agusta BA609 and Boeing Osprey V-22 (see Figure 4). The Agusta BA609 is now at an advanced point of certification by the Federal Aviation Administration (FAA) and should start production and commercialized service in the first months of 2007, having already met with considerable success. The manufacturer has received about 700 orders from all over the world (Augusta, personal communication). The Boeing OSPREY V-22 is in a renewal phase having already completed many flight hours for verification and certification.

The V-22 has various drawbacks deriving from its implementation and the reason for its creation, being in fact conceived essentially as a war plane.

It has, therefore, some specifications that distance it from the commercial transport field, for example its high noise level goes over the limits imposed by the FAA. The fuselage is very heavy, originally built with materials designed to impede projectiles in a war situation. It has limited maneuverability and is a heavy workload for its pilots. However, it is presumed that some of its problems will be resolved in the near future (Jaworowski & Dane, 2003).

Apart from the two models already described there are, of course, others in various stages of development, due to the need to improve their properties, especially in terms of the number of passengers carried. Both NASA and space agencies in Europe have carried out studies and begun planning and feasibility studies of the various models, having already carried out research regarding replacement of 30-40 passenger (pax) jets. Studies of the European Future Advanced Rotocraft (EUROFAR) 30 pax started in 1988 and it is expected to be produced in three different versions.

Figure 4. The Agusta BA609 (left) and the Boeing Osprey V-22(right) tiltrotors



Agusta, utilizing previous research and prototype experience and also data coming from ERUOFAR, has set up the planning of a new convertible plane called the Enhanced Rotorcraft Innovative Concept Achievement (ERICA). ERICA will succeed the EUROFAR. This represents a new model of the tiltrotor concept, as it will be a union of the concepts coming from the EUROFAR 30 pax and the BA609 projects, in addition, more technologically advanced solutions will also be introduced. An innovative solution is represented by the fact that a portion of the wings is attached to the engine. This is a particularly important aspect in that it greatly reduces the aerodynamic drag produced by the wing surface during vertical take-off, giving the aircraft a much easier take-off with less fuel consumption.

Advantages of the Civil Tiltrotor (CTR)

In synthesis, tiltrotors compared to traditional airplanes have:

1. The possibility of rapidly ascending and descending;
2. Great maneuverability, even at low speeds, which permits a very steep glide slope for approach and take-off, thanks also to their responsiveness in reacting to commands;
3. A not-necessarily fixed approach direction for LTO;
4. Excellent maneuverability at low speeds which gives flight precision during the final phases of landing, ensuring a minimum occupation of airspace; and
5. Extreme flexibility at low speeds making it less sensitive to adverse atmospheric conditions as compared to traditional fixed-wing aircraft.

For all this, if tiltrotors are forced to function within the same approach and take-off lines as traditional aircraft, the potential of the CTR will be negated. That is why the introduction of suitable, independent procedures is needed in order to allow them to be fully exploited. This system would be simultaneous and non-interfering (SNI) and allow a combination of the aircraft's peculiar features with control procedures and flight rules be based on its specific performance so that instrument flight rules (IFR) simultaneous and independent operations are possible. The system is based on the differentiation of the final approach and take-off area (FATOs) for V/STOL and on establishing new instrumental standard flight paths associated to transition corridors for V/STOL ascent and descent. Therefore, SNI operations complete the standard arrival system, by introducing steeper instrumental approaches to a separate touchdown and lift-off area or a parallel/converging runway.

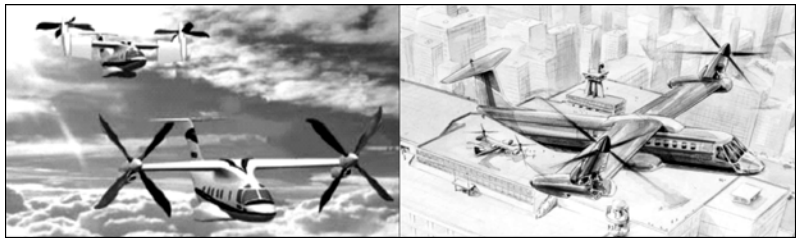
Actually, such improvements require the full operational application of a GPS to air navigation, which would allow the highest capacity levels to be obtained, even if the microwave landing system and distance measurement equipment approach seems to be a good temporary solution for navigation in the ascent and approach stretches, permitting curved trajectories.

The positioning of the new V/STOL site is regulated by three fundamental parameters:

1. Located far from fixed-wing airplane runways in order to have the maximum independence between operations;
2. Be a relatively short distance from the terminal buildings, a maximum of five miles, so as not to lose the V/STOL's advantages of speedy air transfer due to excessive ground transfer times; and
3. Near to the existing airport structure in order to minimize the noise effect; however, as shown in Figure 5, V/STOL noise

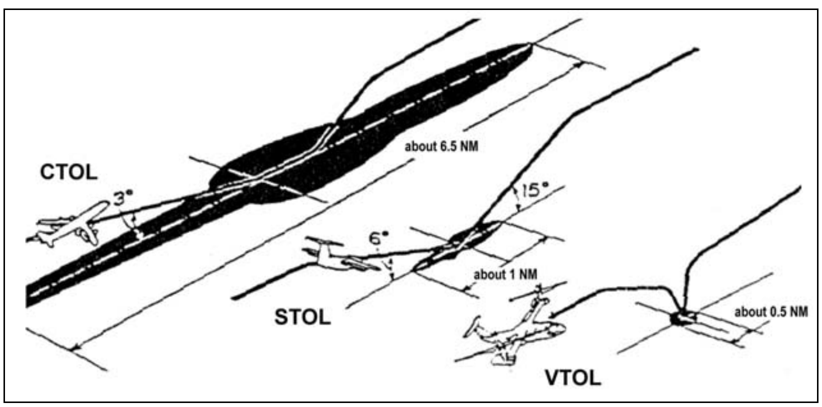
tracks are smaller than CTOL ones, due to the steeper climb and approach path angles.

Figure 5. The new concepts of Enhanced Rotorcraft Innovative Concept Achievement (left) and European Future Advanced Rotorcraft 30 passenger (right) tiltrotors



Many studies have been carried out about the noise effect of tiltrotors and there is no doubt that this problem could create environmental limits for the civilian use of tiltrotors, especially near urban areas. One study was performed in which the noise levels of the EUROFAR 30 pax tiltrotor and a normal transport aircraft were compared in zones in the immediate vicinity of an airport. This kind of research found that a CTR has a noise level that, in vertical flight configuration, is comparable to that of a normal large helicopter and even as much as three effective perceived noise levels less.

Figure 6. Comparison of noise tracks for aircraft with conventional take-off and landing (CTOL), short take-off and landing (STOL) and vertical take-off and landing (VTOL)



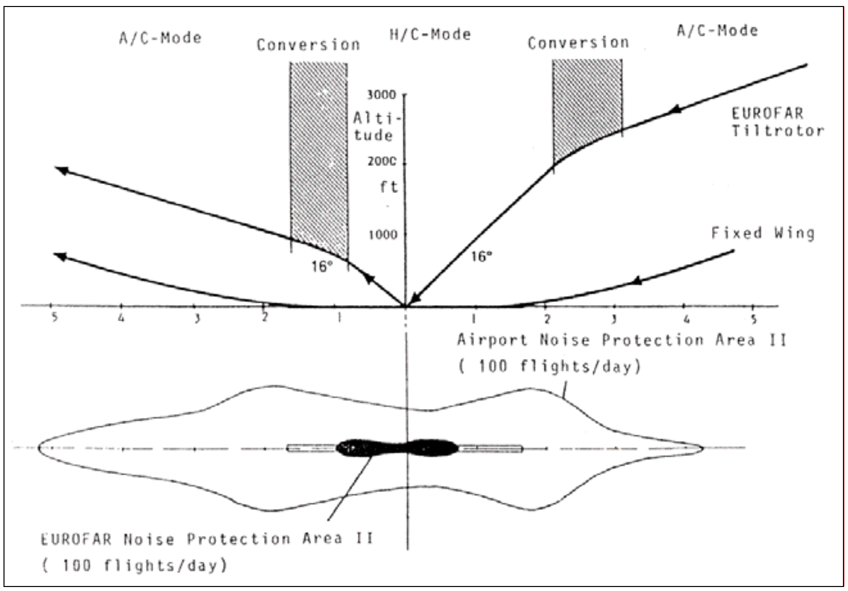
Source: Ferrara, 2002

At the same time, the noise level of a CTR is higher than that of a traditional airplane, particularly during take-off. These results are shown in Figure 6, in which the airport protection area and the noise restraints imposed by the International Civil Aviation Organization certification are highlighted. From this figure it can be seen that if tiltrotors were used in vertical flight mode in a normal airport, the protection zone could be reduced considerably.

Operating costs

The authors are carrying out a study aiming at the definition of the operating cost of the tiltrotor, in comparison with other aircraft, used for regional air services. These aircraft are the: (a) ATR-42; (b) Cessna Citation 2; and (c) Bell Helicopter 412EP. Figure 7 shows some crucial data of these aircraft, in terms of general features, performance and costs. Some data have been provided directly or indirectly by the manufacturers, and the others have been calculated.

Figure 7. Tiltrotor and fixed-wing airport noise protection areas



Source: Ferrara, 2002

Operating costs are divided into direct operating costs (DOC) and indirect operating costs (IOC). The DOC concern all the activities that are directly connected to the transport service; they include fuel consumption, crew wages, maintenance costs, and also amortization and assurance costs. The IOC depend on the general layout of the company and its management criteria.

Taking into accounts both the operating costs and the general features of the considered aircraft (especially the maximum passenger pay load), we get a (rough) estimate of the breakeven fare, which is the fare to apply to meet exactly the cost of the service, without any profit. The values shown in Figure 7 refer to an IOC incidence of 30% and a load factor of 60% and are expressed in dollars per passenger per hour.

As a result of these estimates, the 9-seat tiltrotor operating costs (and the breakeven fares) seem to be at the same level than the ones typical of the regional turbojets, thus confirming two facts:

1. The present tiltrotor can be a convenient alternative to the regional turbojets along short distances, where the speed gap can be covered by the lower terminal time; and
2. Future CTRs, with a pay load of about 30 pax, may be even more convenient, assuming that operating costs increase less than proportionally with the number of seats.

Disadvantages of the CTR

Until a few years ago the use of this type of rotating wing aircraft within airports as regular scheduled transport was not feasible, given that procedures specifically studied for IFR flights did not exist. Having to follow standard LTO procedures made it impossible for V/STOL craft to maintain the regulation speeds (to name just one parameter) because the standard approach speeds were studied for faster machines. For this reason it was not possible to complete this phase within the assigned slot, thereby occupying more than one. This is why it is often preferable to follow the general aviation norms, that is, contact flying and low altitude flying, negating its potential for IFR flight. New flight procedures come from this need to modify the present state of affairs, which as regards airport airspace means, steeper approaches, instrumental flight with the help of precision GPS, and other elements.

With the new CTR models some problems have been resolved that, during the years, have heavily penalized and continue to penalize other V/STOLs, for example high maintenance costs due to mechanical complexity and critical conditions of usage or environmental problems (noise) linked to the features of the craft and the type of usage (e.g., at low quota or not, or whether over urban or rural areas). Up to now these limiting factors have been the reason why use of this vehicle has not been more widespread, especially in areas in which they do not operate but in which suitable conditions for their use could exist.

THE CIVIL TILTROTOR AND AIRPORT CAPACITY

Delays due to airport overcrowding and congestion cost international air carriers approximately 4 billion dollars in 2000 and an estimated 5.2 billion dollars in 2004. The European Commission estimates the cost of delays in 2000 due to air traffic congestion was 3.8 billion Euro. This situation is matched by the fact that inter-European flight departures have an average delay of 15 minutes in 28.3% of cases (Ferrara, 2002). It can be noted that more air traffic means not only more traffic in the sky but also more activity and obstructions on the runways and apron, as well as inside the airport landside.

The airport capacity

An airport's capacity is defined as the number of flights (landings and take-offs) that can be carried out within a determined period of time with an average delay falling within acceptable time limits. Considering that with an increase in the number of flights, the average delay also increases, it is therefore necessary to choose a reasonably tolerable delay in order to determine capacity.

Ideal maximum capacity is when the time intervals between successive operations are equal to the respective occupation times of the aircraft using the runway and there is no variation either in the time intervals between aircraft or between their runway occupation times. Naturally these are ideal conditions. In practice, during peak periods queues can produce ever increasing delays as the queue lengthens. Therefore, the practical operating capacity of a single runway with many exits can be considerably less than the ideal, according to the amount of delay considered acceptable. Normally four minutes is held to be acceptable (Ignaccolo & Inturri, 2001).

Airport capacity depends on factors such as the layout of the aerodrome, the runways and taxiways, the characteristics of the aircraft using the airport, weather conditions and control techniques for air traffic management in the terminal area.

Why the tiltrotor may increase capacity

In the 1960s and 1970s when the first studies regarding the V/STOL concept were carried out, it was already time to start resolving specific problems such as excessive connection times between the starting points and destinations of a journey and the airports and the lack of really convenient alternative solutions to road or rail connections over short-to-medium distances. The same can be said of technical capacity, such as excessive consumption of fuel by the engines of that time, excessive noise and pollution, and considerable plane weight requiring the use of oversized engines needing greatly increased fuel loads.

The idea of using tiltrotors within airports for regional/inter-regional airport movements with the primary aim of increasing capacity came from a renewed interest in the market for such machines. The reasons are obvious, in that:

1. They constitute a really valid, competitive substitute to other highly expensive and not easily accomplished solutions (the building of new runways for example); and
2. They can replace planes of an equal capacity because their particular design characteristics make them highly versatile and easy to handle.

Estimating capacity increase

In this section of the paper we try to establish quantitatively the contribution in terms of capacity resulting from the use of tiltrotors as substitutes for medium capacity planes, using the Blumstein model for movements relating only to arrivals (Horonjeff & McKelvey, 1994). We have referred, therefore, to an airport using only one runway and for which the precise composition in terms of aircraft types using the terminal area is known.

For this part of the analysis we do not refer to the use of CTRs in completely vertical take-off mode, but imagine their use only in short take-off mode. Compared to a turboprop aircraft, the CTR has the ability to land and take-off in relatively short distances of around 600-1,000 feet with a runway occupation time of less than 35 seconds. We also considered a descent path equal to 2.5 nautical miles (NM), as stated in the producer's technical specifications, and less restrictive separation spaces than those of the turboprop, given the low level of disturbance caused by turbulence coming from the wake vortex of preceding planes.

In the following tables the data used for determining airport capacity are estimated for three case studies:

1. Without tiltrotors;
2. Using CTRs to completely replace medium aircraft;
3. Using CTRs in an ever-growing percentage of substitution for heavy and large aircraft.

Table 2 shows the types of aircraft considered for the relative percentages and ground speeds, as well as the relative runway occupation times once the craft has landed and finally the length of the common descent path. The space separations among aircraft types, due to wake vortex effects, are shown in Table 3.

Table 2. Aircraft compositions and characteristics for airport capacity evaluation

Aircraft Type	Composition Case Study 1	Composition Case Study 2	Final Approach Speed [kts]	Final Approach Speed [km/hr]	Runway Occupancy Time [seconds]	Common Path Length [nm]
Heavy	30%	30%	140	259.84	70	5
Large	30%	30%	125	232	60	5
Medium	35%	0%	110	204.16	55	5
Small	5%	5%	90	167.04	50	5
V/STOL	0%	35%	100	185.6	35	2.5

V/STOL – aircraft capable of vertical and short take-off and landing

Table 3. Space separations among aircraft types, in nautical miles

Preceding Aircraft Type	Aircraft Type: Heavy	Large	Medium	Small	V/STOL
Heavy	4	5	5	5	4
Large	2.5	2.5	2.5	4.5	2
Medium	2.5	2.5	2.5	4	1.9
Small	2.5	2.5	2.5	2.5	1.9
V/STOL	2.5	2.5	2.5	4	1.9

V/STOL – aircraft capable of vertical and short take-off and landing

Referring to the Blumstein model, it is possible to calculate the time separations among the aircraft types. These are presented in Table 4.

Table 4. Time separations among aircraft types, in seconds

Preceding Aircraft Type	Aircraft Type: Heavy	Large	Medium	Small	V/STOL
Heavy	102.86	128.57	128.57	128.57	102.86
Large	79.71	72.00	72.00	129.60	60.00
Medium	99.35	91.64	81.82	130.91	62.18
Small	135.71	128.00	118.18	100.00	88.40
V/STOL	100.00	100.00	100.00	160.00	68.40

V/STOL – aircraft capable of vertical and short take-off and landing

These values lead to a capacity estimate for a runway used only for arrivals in Case Study 1, with no use of tiltrotors, equal to 36.71 movements per hour. For Case Study 2, we assume a complete substitution of the medium aircraft with tiltrotors. The time separations do not vary, while the compound probability P_{ij} of having an aircraft of type *j* following an aircraft of type *i* varies with respect to Case Study 1. For Case Study 2 the runway capacity is equal to 38.55 movements per hour.

The increase in airport capacity from Case Study 1 to Case Study 2 is quite slight, about 5%. Obviously, when the percentage of medium aircraft is greater than that (e.g., in regional airports), the capacity increase may be more relevant.

On the other hand, for congested airports, even a slight increase in airport capacity can lead to a significant decrease in the average delay suffered by all aircraft, thus lowering operating costs and making that airport more attractive to them.

Hypothesizing an ever-growing percentage use of the tiltrotor, which corresponds to the introduction of larger crafts, we calculated the respective increase in airport capacity, which is shown on Table 5.

Table 5. Estimates of airport capacity increase for five case studies of varying aircraft composition

	Size/type of aircraft						
Case Study	Heavy	Large	Medium	Small	V/STOL	Capacity [movements/hour]	% Increase
1	30%	30%	35%	5%	0%	36.71	
2	30%	30%	0%	5%	35%	38.55	5.00%
3a	20%	20%	0%	5%	55%	40.80	11.14%
3b	15%	15%	0%	5%	65%	42.29	15.18%
3c	10%	10%	0%	5%	75%	44.07	20.03%
3d	10%	10%	0%	2%	78%	45.74	24.58%

V/STOL – aircraft capable of vertical and short take-off and landing

Capacity for CTR exclusive runways

The situation examined does not presume using a CTR capable of vertical take-off, but instead imagines using a version capable of short take-off. The commercial tiltrotor can board a greater number of passengers and take-off in a greatly reduced space, not vertically, but still with relatively shorter distances than those necessary for normal fixed wing aircraft.

The FATO for an aircraft using VTOL can be any surface (about 1,000 feet long)—both inside or outside the airport—that can be used as a LTO area. It could therefore be a taxiing area, or a runway no longer in use, or a segment of a secondary runway used for STOL operations. Once the steep descent starting point had been reached or when ATC requests it, a descent procedure with elevated glide slopes and maximum speed up to the touchdown zone would begin.

The concept of minimum speed associated with the IFR flight certification disappears with the tiltrotor's capability to conserve all its maneuverability even at very low speeds. In the absence of a lower speed limit for approach the potential steepness of the descent path can comfortably reach 12/13 degrees. Simulations have even foreseen a capacity to operate with glide slopes at speeds of less than 50 knots. Eventually approach/take-off paths could be defined that are considerably narrower than the present ones so as to minimize the airspace necessary compared to the present standards for traditional planes.

The areas destined for the transition phase will have to be reserved areas, in order to carry out the conversion from ordinary plane mode to that of HELO mode. This is to avoid interfering with the normal operations of fixed wing aircraft in departure/take-off or approach/landing on the main runways. It must, of course, be emphasized that such areas will be airspaces in which operations will strictly follow procedures. The capacity to land in IFR independently of the rest of the traffic is an essential requisite in order to increase airspace capacity. Simultaneous, converging instrumental approaches without interference allow traffic to be sorted in the best possible way without extra work for ATC.

The location of potential sites for these new means of transport must pay attention to three particular conditions:

1. Maximum operational independence must be guaranteed;
2. Shortening of transfer times to and from the tiltrotors, both for passengers in transit to and from other aircraft and for passengers departing or arriving, so as to optimize landside sorting; and
3. Minimal acoustic impact on the surrounding territory (reason for locating within the airport itself).

Little-used runways with a length of less than 5,900 feet, called stub runways (Stouffer, Johnson, & Gribko, 2001), are the most attractive for CTR traffic except in the cases where these runways were closed because of interference with the instrument landing system operations of traditional planes, in which case the inter-dependence could have a negative effect on the expansion of capacity.

An alternative to the use of little-used runways would be the use of aprons and taxiways so as not to upset traffic on the flight runways. An attempt was made to identify areas outside airports but in many cases the surrounding zones were already occupied by residential or industrial installations which impeded the creation of exclusive CTR runways. In the cases in which it is possible to locate these areas, it is necessary to keep in mind the problems both of noise pollution and the distance of the CTR terminal from the main terminal, which should not be more than 5 NM in order to not compromise the benefits of using tiltrotors by excessive terminal transfer times.

Airport reconfiguration

Airport reconfiguration, with the hypothetical introduction of such machines, would include the opening or reallocation of runways or taxiways, or even the building of new exclusive runways. The CTR can be used on almost all runways without difficulty, while traditional take-off aircraft must necessarily be used in airports with suitable runway characteristics and therefore with adequate space according to the type of aircraft.

A NASA study (Johnson, Stouffer, Long & Gribko, 2001) tried to establish for several airports whether it had sufficient space to permit CTRs to operate independently of traditional traffic. This information is valuable due to the considerable increase in airport capacity that can be obtained in this way. The research took into consideration the infrastructural characteristics of the airport and the existing structures and the location and availability of areas for the new aircraft. The result is a scale of values for operating potential for those American airports at which 85% of passenger traffic movement takes place. The study concluded that only one airport out of the 63 studied did not possess the specific features necessary to permit CTRs and traditional planes to operate independently. The examined interventions and the respective number of airports for which they are feasible are shown on Figure 8.

Figure 8. Comparing the tiltrotor to other conventional aircraft

						
	manufacturer		CESSNA	ATR	BELL	BELL-AGUSTA
	model		Citation 525 Bravo	42	412EP	BA609
	type		turbojet	turboprop	rotorcraft	tiltrotor
	wingspan	ft	52	82	-	59
	length	ft	46	75	43	43
	max load	pax	10	50	14	9
	range	NM	1.890	1.000	375	750
	max cruising speed	kts	400	300	125	275
	min takeoff distance	ft	3.400	4.800	0	0
	min landing distance	ft	3.000	3.600	0	0
	MTOW	kg	6.500	18.600	5.200	7.300
	operational ceiling	ft		18.000		25.000
	approximate price	M$	4,4 (1997)	12,2 (1994)	4,9 (1999)	9 (1998)
DOC	administration	$/h	231	645	433	355
DOC	crew	$/h	270	534	202	202
DOC	maintenance	$/h	383	485	362	294
DOC	fuel and oil	$/h	314	725	186	203
	total DOC	$/h	1.197	2.389	1.182	1.053
DOC+IOC	IOC 20%	$/h	1.436	2.866	1.418	1.264
DOC+IOC	IOC 30%	$/h	1.556	3.105	1.537	1.369
DOC+IOC	IOC 40%	$/h	1.676	3.344	1.655	1.474
	breakeven fare	$/paxh	259	104	183	254

MTOW – Maximum take-off weight
IOC – Indirect operating costs
pax – passengers
kts – knots
M$ - millions of dollars U.S.
$/paxh – dollars per passenger per hour
DOC – Direct operating costs
ft. – feet
NM – nautical miles
kg – kilograms
$/h – dollars per hour

The type of capacity increase considered is in terms of an increase in independent or dependent operations that allow an increase in the number of supplementary flights and that improve the time flow of other airports. The number of additional operations depends not only on the runway types, but especially on the layout of the whole airport infrastructure and the respective runway configurations. For example, a new independent runway can permit about 70 operations per hour, but if the runway is not completely independent that value decreases considerably. The FAA regulations establish that independence between two parallel runways takes place at the moment in which there is a distance of more than about 4,200 feet between them. If the distance is less then 4,200 feet, they are dependent runways on which operations are carried out under IFR control. Completely independent operations make the greatest contribution to an increase in capacity. This is realized when a new runway can be built at about one NM from preexisting runways so as to give approaching aircraft two parallel, simultaneous and completely separate approach routes.

It is evident that the problem of insufficient airspace capacity can find an immediate solution in the operative use of new generation CTRs, rationalizing the use of traditional aircraft and adapting flight procedures for V/STOL, particularly in view of their future implementation in airports.

CONCLUSION

It appears clear how the problem of insufficient airspace capacity can be rationally faced. It means that starting from now the operational use of the new generation of craft must be programmed, rationalizing the use of existing aircraft and adapting flight procedures for rotating-wing craft especially in view of their future use in airports.

The results coming from different studies must be kept in mind, particularly those indicating that the use of tiltrotors would represent a fraction of the cost of the necessary structural enlargements, but that if used correctly could lead to an increase in capacity equal to that obtainable from the building of a new runway, besides other effects such as increasing the number of available slots (quantifiable as 50% of arrivals and departures, 40% during peak hours).

In conclusion, the introduction of the new V/STOL can represent the least expensive, most efficacious and safest way of improving airspace flexibility and productivity by reducing delays and increasing capacity.

It can be understood that the introduction of these craft and the parallel development of optimal procedures for their use together represent an optimization of the use of airspace capacity without involving disproportionate additional costs and at the same time leading to a significant improvement in airport performance.

Nevertheless, there is a great deal of skepticism on the part of ATC authorities and the airlines themselves of changing immediately to the use of tiltrotors. The airlines in particular, who would benefit only indirectly from an increase in airport capacity, need to thoroughly understand the simulation data and examine performance before placing orders that could turn out to be uneconomic.

It is the opinion of the authors that if the tiltrotor's passenger transport capacities are confirmed and models with a suitable capacity for commercial service are produced, the choice of these aircraft could be one of the best solutions to the often-posed question of how to improve airport congestion without extending the infrastructure.

REFERENCES

Bombardier (2001). Regional Market Outlook.

ERA, European Regions Airline Associations (2002). Statistics. *http://www.eraa.org/stats.asp*

Commission of the European Union (Unknown date). The potential benefits of V/STOL fro alleviating Air Traffic Control delays, Airport/4 study.

Ferrara S. (2003). L'uso del convertiplano nel trasporto aereo regionale, Degree Thesis, University of Catania.

Graham B. (1997). Regional airline services in the liberalized European Union single aviation market. *Journal of Air Transport Management, 3(4),* 227-238.

Horonjeff, R. & McKelvey, F. X. (1994). ***Planning and design of airports.*** New York: McGraw-Hill.

Ignaccolo M. & Inturri G. (2001). Modelli analitici e di simulazione per la valutazione delle prestazioni in ambito aeroportuale. In Cantarella, G. E & Russo, F. (Eds.), Metodi e tecnologie per l'ingegneria dei trasporti. Milano: Franco Angeli.

Jaworowski R. & Dane, W. (2003) The world rotorcraft market 2003-2012.*Vertiflite, 49(1)*, 10-17.

Johnson J., Stouffer V., Long D., & Gribko J. (2001). *Evaluation of the national throughput benefits of the civil tiltrotor.* NASA/CR-2001-211055. Washington DC: National Aeronautical and Space Agency.

Schmitt D. (2001). Challenges for unconventional transport aircraft configurations. *Air & Space Europe, 3(3/4),* 67-71.

Stouffer V., Johnson J. & Gribko J. (2001). *Civil tiltrotor feasibility study for the New York and Washington terminal areas*. NASA/CR-2001-210659. Washington DC: National Aeronautical and Space Administration.

US DOT, Department of Transportation (1995). Civil Tiltrotor Development Advisory Committee, Report to Congress in Accordance with PL 102-581, December 1995.

APPENDIX

List of Acronyms and Abbreviations

A/C	aircraft
ATC	air traffic control
CTOL	aircraft using conventional take-off and landing mechanisms
CTR	civil tiltrotor
DOC	direct operating costs
ERICA	Enhanced Rotorcraft Innovative Concept Achievement
EUROFAR	European Future Advanced Rotocraft
FAA	Federal Aviation Administration
FATO	final approach and take-off area
GPS	global positioning system
HELO mode	flying a V/STOL in helicopter mode
IFR	instrumental flight rules
IOC	indirect operating costs
LTO	landing and take-off
MTOW	maximum take-off weight
NASA	National Aeronautics and Space Administration
NM	nautical miles
pax	passengers
SNI	simultaneous non-interfering
STOL	short take-off and landing
V/STOL	aircraft capable of vertical or short take-off and landing
VTOL	vertical take-off and landing