CHAPTER 3

tiltrotor System Issues

CONTENTS

Boxes

Figure

Tables

CHAPTER 3

tiltrotor System Issues

A major irony of the jet age is that most of the time spent in airline travel is on the ground. For airline trips under 700 miles or so, passengers spend over one-half their total journey's time on the roads surrounding airports, at the terminal, and in the aircraft while it taxis and waits for takeoff clearance or an available gate after landing.[1] Ever since helicopters entered civilian service soon after World War II, transportation planners have envisioned intercity air travel virtually from doorstep to doorstep. Proponents claim that tiltrotor aircraft, which can fly like both helicopters and airplanes, hold the promise of such service at trip costs comparable to freed-wing aircraft flights and offer options to increase the capacity of congested airports. However, there are enough concerns about community acceptance, adequate infrastructure, and market demand that private industry is not yet willing to risk investment capital to develop commercial tiltrotor aircraft.

The helicopter is the most familiar aircraft design with vertical takeoff and landing (VTOL) capabilities but has never been widely used for scheduled intercity transportation. Fundamental speed and payload limitations put helicopters at a distinct economic disadvantage to comparable commuter turboprop aircraft, whose operating costs are three to five times lower.[2] However, many other VTOL concepts, including some with the performance potential of conventional airplanes, have been examined during the past four decades.[3] The National Aeronautics and Space Administration (NASA) and the U.S. military are developing one such VTOL vehicle, a tiltrotor called the V-22 Osprey,[4] which has pivoting engine/rotor assemblies mounted on each wingtip. The aircraft operates like a helicopter when the rotors are in the vertical position, but when the rotors are tilted forward 90 degrees, the tiltrotor flies like an airplane. tiltrotors and similar "powered-lift" vehicles bridge the speed and range gaps between helicopters and airplanes.[5] Possible applications for tiltrotors include helicopter missions where increased speed and range are important, such as search-and-rescue missions, and conventional fixed-wing flights where avoiding air and ground congestion, delays, or restrictions is particularly valuable. However, the focus of this study is on tiltrotor use for scheduled intercity travel only.

The V-22 Osprey, currently under full-scale development for a variety of military missions, is the technology base for a U.S. civil tiltrotor. Five V-22 aircraft are to be used in the flight test program. As of June

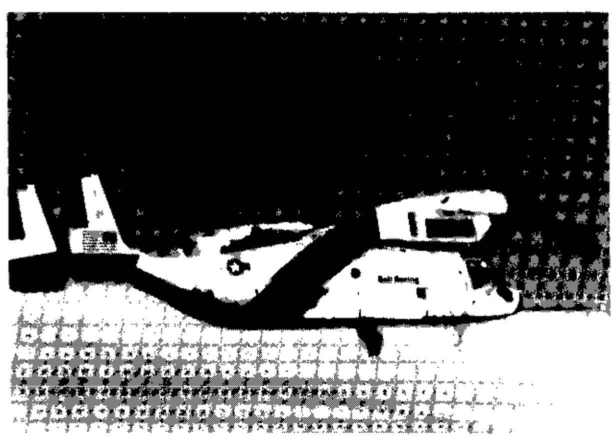


Photo credit: Bell Helicopter Textron, Inc.

Designed for a variety of military missions, the V-22 Osprey tiltrotor is now in full-scale development.

1 Bell Helicopter Textron, "Tiltrotor: A National Transportation Asset," promotional booklet, n.d.

2 David Lawrence, "Helicopters and Today's Air Transportation System," *Transportation Quarterly*, vol. 45, No. 2, April 1991, p. 164.

3 However, the only vertical takeoff and landing designs that have gone into production are helicopter and vectored-thrust military jets.

4 The National Aeronautics and Space Administration developed a tiltrotor research aircraft known as the XV-15 in the 1970s. The current Department of Defense tiltrotor program is for a larger, multipurpose tiltrotor, the V-22 *Osprey.*

5 *The* Federal Aviation Administration certification standards cover three broad classes of aircraft: airplanes, rotorcraft, and manned balloons. Powered-lift aircraft establish a new category since they can fly at high speeds like airplanes and go slow, possibly hover, and takeoff and land vertically (or near vertically). These vehicles use jet or rotor thrust for lift, control, and propulsion—hence the term "powered-lift." Airplanes create lift primarily from the airflow over the wings that results from vehicle movement; thrust is fore and aft only, and contributes little to control and lift.

1991 these aircraft have accumulated more than 550 flight hours.[6] U.S. manufacturers could develop and produce a market-responsive[7] tiltrotor by the end of this decade if favorable travel demand estimates are established and supportive national transportation policies are put in place.

The Department of Transportation and NASA are conducting modest tiltrotor research and development (R&D) and operational feasibility and market assessment studies. Since 1988, the Federal Aviation Administration (FAA) has awarded grants for 17 vertiport planning and feasibility studies, most of which should be completed by the end of 1991. FAA NASA and the Department of Defense (DOD) have jointly funded studies[8] examining civil applications and promising markets for tiltrotor technology, and the latest study concludes that civil tiltrotors could be competitive with fixed-wing aircraft in certain markets, provided adequate air and ground infrastructure is in place and tiltrotor operations prove to be acceptable to communities, air carriers, and the traveling public (see box 3-A).[9]

tiltrotor technology may have implications for national competitiveness in aviation industrial base strength, international technology leadership, balance of trade, and domestic transportation productivity. Currently, the United States has more than a 5-year development lead worldwide in tiltrotor technology.[10] Over one-half the potential demand for commercial tiltrotors lies overseas.[11] OTA has recently completed, or has under way, studies on international trade and industrial policies, including aviation industry issues regarding Japan and Western Europe.[12]

There is also foreign interest in developing high-speed VTOL aircraft and in producing commercial products. Eurofar, a European consortium of five helicopter manufacturers, has plans to develop a commercial tiltrotor prototype over the next 5 years, with support from their governments. Japan is hoping vertical flight will overcome some of its severe transportation constraints. A Japanese organization has announced plans to construct a network of over 3,000 heliports across the country by 2020.[13] After viewing a V-22 flight demonstration at Bell Helicopter's Fort Worth plant, Japan's Minister of International Trade and Industry reportedly said, "If you build it, we will buy it. If we can't buy it from you, we will build it."[14] Japan's Ishida Group is financing the development of a 14-passenger tiltwing for corporate and business markets.

Tiltrotor System Concepts

As a basis for discussion of commercial tiltrotor technology and its potential for intercity transportation, this section describes a generic, commercial passenger tiltrotor system. The description is not meant to imply that the concept is practical or recommended. tiltrotor applications other than common carrier service are not considered.

Congestion Is the Key

Transportation limitations within our busiest intercity corridors make tiltrotor service potentially attractive. Traffic delays on the roads and airways surrounding airports lengthen an air traveler's journey, and coping with future aviation traffic growth will entail changes in highway systems as well as airport

6 Stanley W. Kandebo, "Osprey Flight Tests Suspended After Crash of No. 5 Aircraft," Aviation *Week & Space Technology,* vo1. 134, No. 24, June 17,1991, p. 54.

7 The V-22 design is not considered suitable for most commercial applications (see later sections).

8 Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987); and Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautic and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

9 Boeing Commercial Airplane Group et al., Phase II Draft Final Report, Op. cit., footnote&p. 1-3.

10 Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, July 18,1991.

11 Boeing Commercial Airplane Group et al., Phase 11 Summary, op. cit., footnote 8, p. 23.

12 U.S. Congress, Office of Technology Assessment, *Competing Economies: America, Europe, and the Pacific Rim* (Washington, DC: U.S. Government Printing Office, in press).

13 Japan Heli Network Co., Ltd., promotional materials for Helicopter Association International Heli-Expo 90, Feb. 4-6,1990, Dallas, TX.

14 Frank J. Gaffney, Jr., director of the Center for Security Policy, testimony at hearings before the House committee on Public Works and Transportation, Subcommittee on Aviation, Apr. 25,1990.

Box 3-A-Federally Funded Civil tiltrotor Studies

The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) began to consider civil applications of tiltrotors seriously during the early 1980s, after the military decided to develop tiltrotor technology for a new multiservice, multimission vertical takeoff and landing (VTOL) aircraft. In 1985 FAA proposed a joint civil tiltrotorstudywith NASA and the Department of Defense (DOD) to ". . . assess the broader implications of the V-22 aircraft development to the nation as a whole. This includes the potential for other versions and sizes, both civil and military, civil certification issues, civil production impact on the defense industrial base and any indirect technology spinoffs. . . ."[1] NASA DOD, and FAA awarded a $1-million study contract to Boeing Commercial Airplane Co., teamed with Bell Helicopter Textron Inc., and Boeing Helicopters to investigate potential commercial, corporate, and public service markets, ground and air facility requirements, and various aircraft configurations and technologies (see figure 3A-l). The summary final report, ***Civil tiltrotor Missions and Applications:*** *A Research Study*, published in July 1987, concluded that a 39-passenger version with a pressurized fuselage had significant market potential resulting from reduced ground transportation requirements, congestion relief, and infrastructure investment savings.[2] However, civil tiltrotors would have higher purchase and operating costs than conventional airplanes and would encounter possible stumbling blocks from certification, infrastructure development, public acceptance, and technological maturity. The study concluded that near-term civil tiltrotor development depends on the success of the V-22 program.[3]

NASA and FAA funded a follow-on tiltrotor study[4] by the same contractor team, which financed 45 percent of the project costs. This "Phase II" study focused on the commercial passenger market and investigated in greater detail the operational factors and technology development considerations. The study found that commercial tiltrotor purchase price and operating costs will likely be significantly lower than estimated in the Phase I report, resulting in an expanded potential market. However, the gist of the findings were similar to, but more detailed than, those in the preceding report. Specific urban-to-urban and hub airport feeder routes offering strong market potential were examined in detail. In certain markets, costs to passengers for ground transportation and airline tickets were found to be less via 39-seat commercial tiltrotors traveling between well-situated landing facilities than via trips on similarly sized airplanes flying out of major airports.

The Phase II study recommended forming a public/private partnership of organizations representing Federal, State, and local government and industry interests to create a 4-year program,[5] costing roughly $250 million,[6] to assess the national benefits of a commercial tiltrotor system and to determine if such a system would be feasible. The Phase II study recommended that the Department of Transportation take a leadership role in forming the partnership. Industry and government support and participation would be essential, and the centerpiece of the program would be a series of operational demonstrations using XV-15 and V-22 tiltrotors. Commercial product development or production was not proposed.

Since 1987, FAA has allotted $2.94 million in Airport Improvement Program planning grants to local sponsors across the United States for 17 vertiport feasibility studies. The studies arc examining the capital costs and environmental factors in siting vertiports, passenger and shipper demand, traffic forecasts, and the local economics of tiltrotor service. Most of the studies are to be completed by late 1991. FAA and the Volpe National Transportation Systems Center are further examining the cost and market potential of commercial tiltrotors and, through simulations, estimating the effects of tiltrotor operations on airspace congestion and delays.[7]

1 Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987), p. 6.

2 Ibid.

3 Ibid., p. 16.

4 Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: February 1991).

5 Ibid., phase II Summary, p. vi.

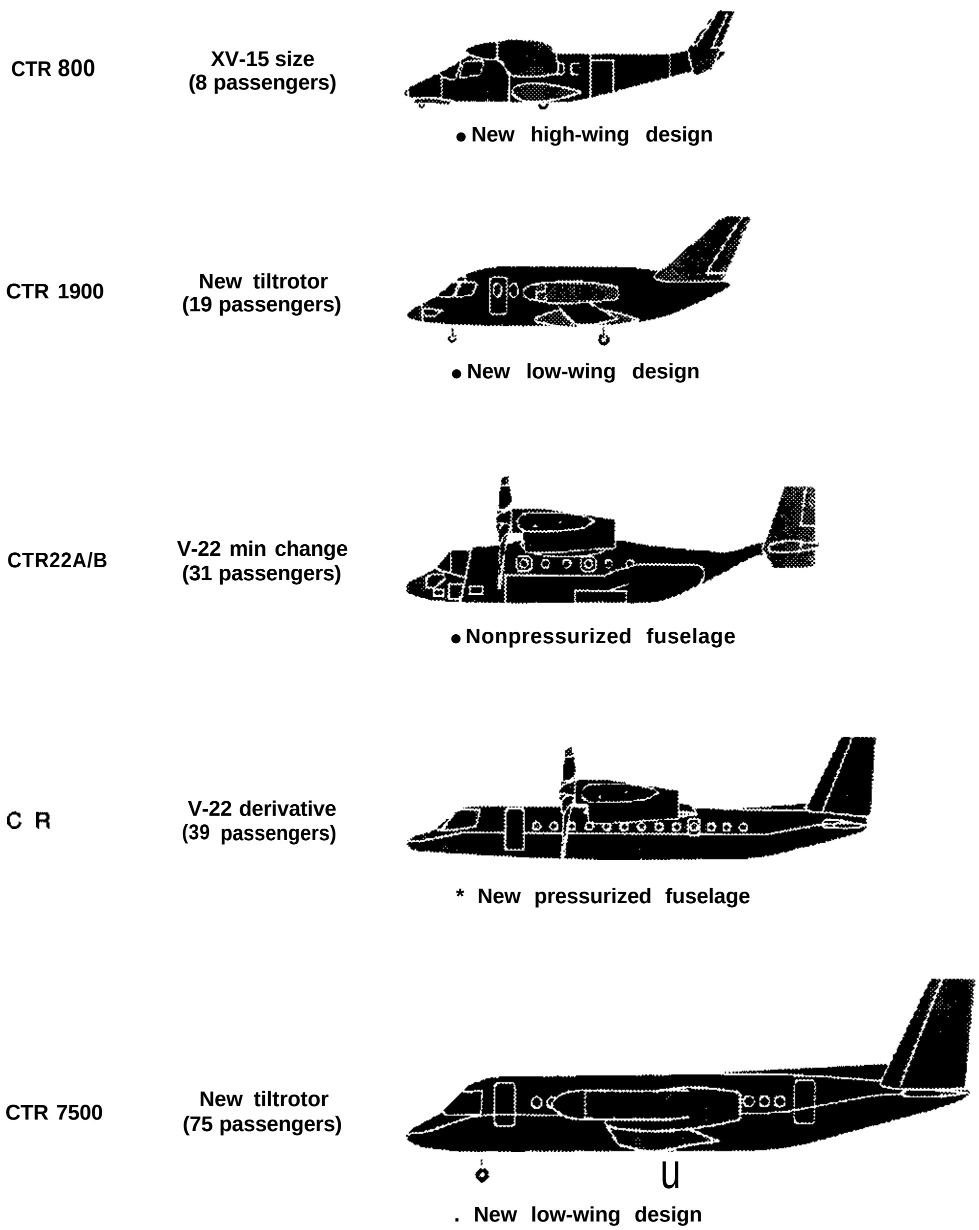
6 John Zuk, Chief, Civil Technology Office, NASA Ames Research center, personal communication, Apr. 11, 1991.

7 John P O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28, 1991.

Continued on next page

Box 3-A, continued

Figure 3A-1—Tiltrotor Configurations



SOURCE: Boeing Commercial Airplane Co. et al., *Civil tiltrotor Missions and Applications: A Research Study,* prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (seattle, WA: Boeing Commercial Airplane Co., July 1987).

Photo credit: Bell Helicopter Texiron, Inc.

Accessible vertiports (shown in this artist's conception) will be crucial to intercity commercial tiltrotor service.

infrastructure, especially the number of available runways. However, most metropolitan areas have few options for expanding airports or their surrounding highways. Commercial tiltrotors offer the potential, under various operating and public policy scenarios, to avoid ground and air congestion, relieve some airport congestion, and increase the capacity of constrained airports. The prime markets for tiltrotor operations are expected to be intercity passenger and airport feeder service in the busiest air corridors. The Phase II Civil tiltrotor Report by NASA and FAA indicates that some passengers would have shorter and less costly drives to get to a tiltrotor terminal than to an airport, which would save significant time overall and make door-to-door travel costs comparable to using fixed-wing aircraft service from major airports.ls

Successful commercial tiltrotor service hinges on well-situated landing facilities, or vertiports. Since tiltrotors do not need long runways, 5-acre or smaller vertiports might be built at accessible locations where conventional airports would be environmentally unfeasible or prohibitively expensive, such as over interstate highways or near industrial facilities. Vertiports co-located with airports could permit increased flights to the airport without clogging runways. To take advantage of its flight capabilities, tiltrotors will require some new air traffic control (ATC) technology and

[15] Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, op. cit., footnote 8.

Table 3-1—tiltrotor System Description

Component	Description	Estimated costs
tiltrotor aircraft	A twin-engine commercial tiltrotor derived from the military V-22 would be comparable to a medium-size commuter turboprop and could carry around 40 passengers up to 600 miles. It would be capable of vertical takeoff and landing, but short takeoff and landing rolls would improve payload or range. Tiltrotors could use existing airports, but 40-seat versions would be too large for many heliports. To compete with airline shuttle service, passenger cabin noise, vibration, and overall comfort levels will have to be at least equivalent to that of the newest commuter aircraft, such as the Boeing/DeHavilland *Dash 8-300.*	Compared with turboprop aircraft, a tiltrotor would cost around 40 to 45 percent more to produce and about 14 to 18 percent more to operate (over a 200-mile trip).
Vertiports	Vertiports could ideally be located closer to intercity transportation destinations and origins than are major airports. Design depends on location, but theoretically any site with up to 5 acres and necessary surrounding clear zones and compatible land use. Possible locations include air rights ‘above freeways, waterfronts, parking garage rooftops, industrial areas, and existing small airports, and each vertiport could serve about 1 million passengers annually.	$30 million to $40 million for an elevated metropolitan vertiport.
En route airspace	En route between cities, commercial tiltrotors would fly in the same relatively uncontested airspace between 10,000 and 20,000 feet above sea level used by commuter turboprops. Since tiltrotors are smaller than the aircraft they would replace (in intercity service), more flights would operate in the airspace system for the same passenger total.	tiltrotors are effectively turboprop aircraft when flying en route, so the marginal ATC rests would be the same as those for conventional commuter aircraft. Increased numbers of aircraft operations might require additional air traffic controller positions and facilities.
Terminal airspace	In the airspace surrounding vertiports, optimal flight paths would avoid conflicts with fixed-wing aircraft and permit the steep approaches necessary to minimize tiltrotor community noise levels. This requires ATC procedures and technologies different from those currently used for fixed-wing aircraft and helicopters. Some of these procedures and technologies exist or are being developed. Potential instrument approach paths are steep (6 to 15 degrees) compared with current helicopter and fixed-wing aircraft procedures (3 degrees or less). Operations must not conflict with existing airport traffic patterns.	Other aircraft types would use these technologies and procedures, so development costs need not be attributed solely to tiltrotor.

KEY: ATC=air traffic control.

SOURCE: Office of Technology Assessment, 1991, based on data from Boeing Commercial Airplane Group et al., Civil *tiltrotor Missions and Applications Phase //: The Commercial Passenger Market,* prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

procedures. Additionally, tiltrotor operations must be viewed as acceptable by the local communities, the traveling public, airlines, and financiers. Table 3-1 describes the basic components of a commercial tiltrotor transportation system.

Conceptually, a network of 12 strategically located vertiports could handle most of the intercity passenger air traffic projected for the Northeast Corridor (NEC) in 2000.[16] Frequent tiltrotor departures to each destination (30- to 60-minute intervals)[17] would reduce

16 Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 20.
17 Depending on time of day, this is comparable to current flight frequencies between some of the major Northeast Corridor airports.

Table 3-2—Characteristics of a Hypothetical Northeast Corridor tiltrotor System for Year 2000

Passenger volume	14 million passengers annually[a]
Vertiports	12 nonairport metropolitan locations[b]
tiltrotorfleet	164 40-seat aircraft
Operations	1,524 flights per day[c]
Average trip length	223 miles

[a]Boeing Commercial Airplane Co. forecast. Around 8 million airline passengers traveled between the major Northeast Corridor airports in 1989.
[b]The location and number of vertiports are: New York (6); Boston (3); Washington, DC (2); and Philadelphia (l).
[c]Approximately 250 or so flights per day by passenger airlines currently operate between the major Northeast Corridor airports.

SOURCE: Office of Technology Assessment, 1991, based on data from Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market,* prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

total trip times for passengers by one-third (more than an hour) on average relative to existing airline schedules. (Table 3-2 lists the characteristics of a hypothetical NEC tiltrotor system.) Most of the time saved would result from shorter ground trips to and from terminals.

State of the Technology

VTOL research vehicles that can also operate as fixed-wing aircraft have flown since the 1950s (see box 3-B) —most were initially investigated for military purposes. Modern digital electronic controls, advanced lightweight materials, and more powerful engines have made these concepts more practical for operational use, but only helicopters and vectored-thrust jets (e,g., the AV-8B ***Harrier*** jumpjet) have gone into production.

Military and Civilian Tiltrotor Programs

Military decisions in the early 1980s to develop a multiservice tiltrotor aircraft sparked the interest of some in the civil aviation community who thought that the technology, industrial base, and operational experience of military tiltrotors would help overcome many of the hurdles facing a commercial vehicle. The V-22 full-scale development program began in 1986 under contract to Bell Helicopter Textron, Inc. and Boeing Helicopter Co., and the technical results to date have been promising. First flown in March 1989, the V-22 has demonstrated flight with rotors tilted in all positions and cruise speeds up to 328 miles per hour (mph).[18] The proof-of-concept predecessor to the V-22, the NASA/DOD XV-15 tiltrotor research aircraft, was developed in the 1970s. Two aircraft were built, and both are still being used in civilian flight investigations, such as determining tiltrotor adaptability to urban vertiports.

Over $2.2 billion for V-22 development has been spent or allocated since 1983, but the future of the V-22 is precarious. The program was canceled by DOD in fiscal years 1990 and 1991 budget proposals, only to be reinstated by Congress each time. DOD again requested no funds for the V-22 in fiscal year 1992, and at the time this report went to press, House and Senate Committees on Armed Services had passed authorization bills that included V-22 funding for fiscal year 1992. Full-scale development, including flight tests, has continued, but no production funds have been used. If the V-22 program is continued, limited numbers of military aircraft could be produced by early 1995.[19]

No U.S. company has committed to developing a tiltrotor for revenue passenger operations, and airlines have shown little interest in this technology. Predesign and planning studies have been funded primarily by the Federal Government, with some cost-sharing by industry and local governments. NASA and FAA continue to develop technologies applicable, but not necessarily specific, to tiltrotor.

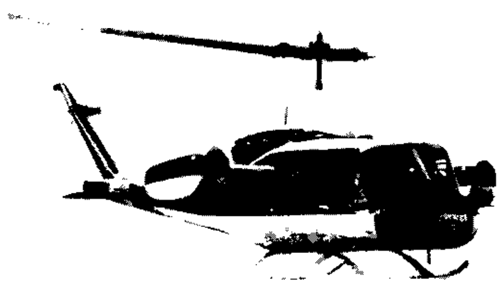
Other High-Speed VTOL Aircraft Programs

Presently, there is little VTOL aircraft competition for the intercity transportation markets that a commercial tiltrotor could serve. New helicopters, such as the Westland/Augusta EH-101, could carry 30 passengers at 150 mph on trips up to 500 miles, but operating and maintenance costs are higher than the figures projected for a civil tiltrotor. It is generally believed that a VTOL aircraft would have to combine some

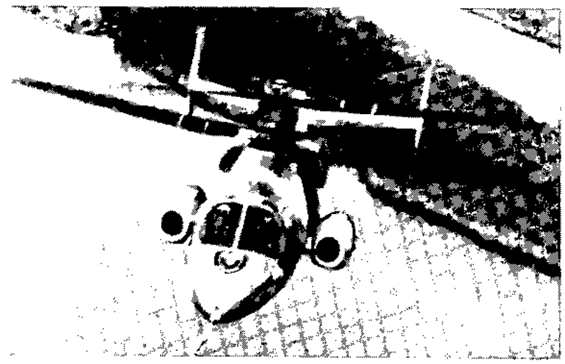
[18]Norwine, Op. cit., footnote 10.
[19]Ibid.

Box 3-B—-VTOL Concepts

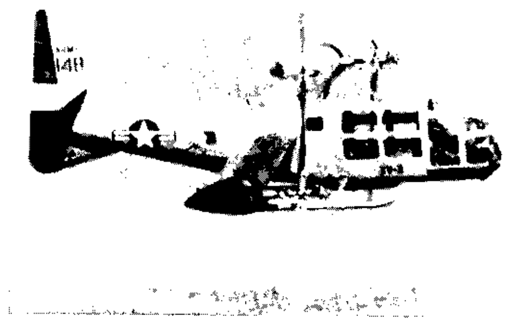
Advanced vertical takeoff and landing (VTOL) aircraft designs aim to exceed the speed and range of helicopters by overcoming rotor aerodynamic limitations. Rotating blades are both the “propeller” and the “wings” for helicopters, and this duality is the key factor that restricts helicopter performance, When a



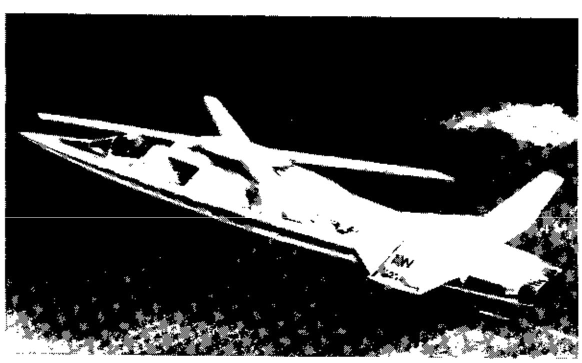
Bell UH-l



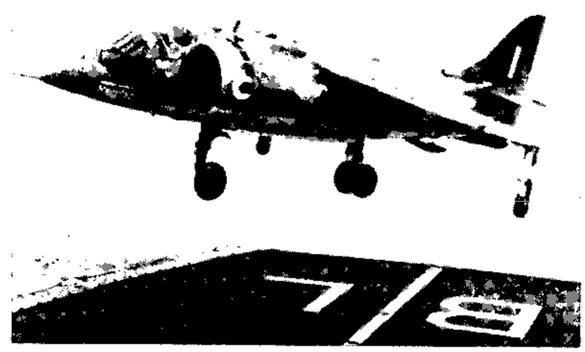
Sikorsky ABC (XI-I-59A)



Bell xv-3



X-Wing



Hawker Siddley Harrier jet

Photo credit: Bell Helicopter Textron, Inc. (XV-3); Sikorsky Aircraft Division of United Technologies

A wide range of vertical takeoff and landing aircraft that could fly faster than conventional helicopters have been examined,

Box 3-B, continued

helicopter hovers, each of its rotorblades experiences the same airflow over its surfaces. As the helicopter moves forward, the retreating rotorblades encounter lower relative winds. Maximum practical helicopter speeds are limited to around 200 miles per hour (mph),[1] at which point the airflow across the retreating blades stalls, causing severe vibration and control problems. Various advanced VTOL aircraft concepts are shown in the photos in this box and some are discussed below.

Compound Aircraft

Some of the lift and propulsive loads on helicopter rotors can be shifted to additional wings and horizontal thrust engines, permitting such a compound helicopter to fly well above 200 mph. A Bell UH-1 helicopter modified with two high-thrust jet engines reached 315 mph. Sikorsky Aircraft Division developed a compound rotorcraft that used two counter-rotating, coaxial rotors for lift, called the advancing blade concept (ABC).[2] Using two horizontally mounted turbojet engines for propulsion, the experimental Sikorsky ABC (XH-59A) reached 275 mph in level flight.

These Bell and Sikorsky compound helicopters were propelled by separate jet engines, making them impractical for commercial purposes. The first compound helicopter using the same engines to power the rotors and to provide significant thrust was the Piasecki 16H-1. A later version, the 16H-1A, reached 225 mph in 1964.[3]

Houston-based Vulcan Aircraft Corporation has been developing a design with lifting fans embedded in the wings. This fan-in-wing concept would receive vertical thrust from the fans for takeoff and landing, then close off the fan disks with louvers and propel itself with jet thrust from the two horizontally mounted engines (which also power the fans). Vulcan's 6-seat aircraft is designed to fly 500 miles and 350 mph. Because the fan disks are relatively small, fan-in-wings require about 10 times more power than a helicopter to lift the same payload.

Tilt-Thrust Designs

Tiltwing and tiltrotor aircraft use the same rotors or propellers for both vertical and horizontal thrust by redirecting the whole wing or the rotor systems only, reducing weight and drag penalties relative to compound helicopters. Lift during cruise is provided by a wing, and maximum speeds are in the turboprop aircraft range of 400 mph. tiltrotors and tiltwings are design compromises between helicopters and airplanes—their rotors/propellers are too small to hover as well as those of helicopters but too large to be efficient in cruise flight. In 1958, the Bell XV-3 became the first tiltrotor to successfully takeoff like a helicopter and then convert to the airplane mode.

Stowed or Stopped Rotor Concepts

Compound helicopters capable of stopping rotors in flight and folding them up or converting the rotors into fixed wings have the highest speed potential of any rotorcraft configuration. One design strategy is to fly the rotorcraft fast enough to transfer lift to separate wings and then stop and fold the rotors. From this point in cruise flight, the aircraft is basically an airplane, and maximum speed is a function of aerodynamic design and engine power. Rotor blades, which are generally flexible, are difficult to stop or start during forward flight because of the severe stresses and forces resulting from the blades' flapping in the wind. A stowed- or stopped-rotor aircraft has never flown. However, full-scale models of both stowed-and stopped-rotor systems

---

1 The world speed record of 248 miles per hour was set by a modified Westland Lynx helicopter in 1986. E.A. Fradenburgh, *Overview ofHelicopters and V/STOL Aircraft and Basic Aerodynamics for Rotor Performance*, Advisoty Group for Aerospace Research & Denvelopment, North Atlantic Treaty Organization (AGARD, Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development, 1990), p. 4.

2 The advancing blades, balanced on both sides of the aircraft, provide most of the lift. Lift from the retreating blades is not critical, and airflow stall is avoided.

3 F.N. Piasecki, president, Piasecki Aircraft Corp., personal communication, July 2, 1991.

Continued *on next page*

Box 3-B, continued

have been tested in the National Aeronautics and Space Administration (NASA) wind tunnels at Ames Research Center.[4]

NASA and the Defense Advanced Research Projects Agency developed and tested technologies for a different concept with very high-speed potential during the 1980s called an X-wing, but the program has been scaled back to a low-level research effort, A four-bladed rotor provides vertical thrust like a helicopter rotor for takeoff and low-speed flight and is stopped and locked into an "X" position relative to the fuselage and serves as a wing for high-speed cruise. The X-wing design, if lightweight enough, could hover as efficiently as a helicopter and fly as fast as a jet.

Vectored-Thrust Vehicles

Deflecting horizontal thrust downward to provide lift has been practical only for jet-powered designs, since this concept requires the most power to lift each pound of aircraft and payload in vertical flight. The British Aerospace/McDonnell Douglas AV-8B ***Harrier*** jet, currently in service with the U.S. Marine Corps, is a vector-thrust vehicle.

All these VTOL concepts pay a price for speed. Useful payload is always less than that carried by a comparably sized helicopter, speed and range are always less than for similar airplanes, and complexity is greater than in helicopters or airplanes. However, the combination of payload, speed, and range may make one of these compromise designs the optimal choice, depending on mission requirements and economics.

[4]John F. Ward, president, Ward Associates, personal communication, June 28, 1991.

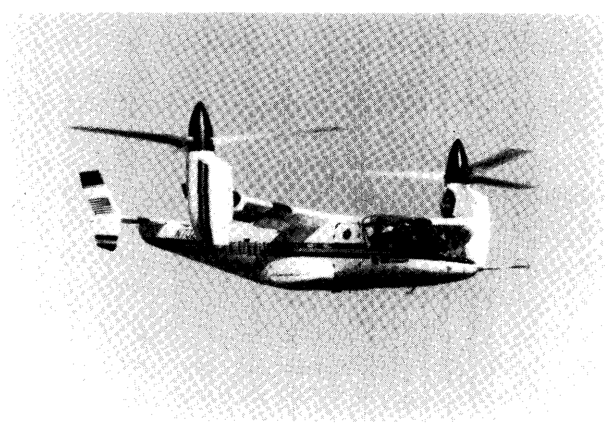


Photo credit: Bell Helicopter Textron, Inc.

After more than a decade of service, two XV-15 research aircraft continue to test and demonstrate tiltrotor technology and flight procedures.

elements of fixed-wing performance to penetrate the intercity transport market significantly. Eurofar has a 30-seat commercial tiltrotor on the drawing board, but the program is probably about 5 years behind U.S. tilt rotor efforts.[20] A U.S. company, Magnum T/l? Inc., of Salinas, California, is proposing to build a 9-seat tiltrotor based on XV-15 technology for the general aviation market.

Ishida Aerospace Research, Inc., a subsidiary of the Ishida Group in Japan, could become the first company producing a high-speed VTOL aircraft for the civilian market. Now in the design stage, Ishida's TW-68 tiltwing aircraft could perform competitively with a civil tiltrotor and be delivered to its first customer in 1997. The 14-passengcr TW-68 is aimed at the private market, such as corporate travel, rather than commercial transportation, although Ishida is applying for the more stringent FAA certification to permit tiltwings to be used in airline operations. Other tiltwing experience includes the LTV-Hiller Ryan XC-142 and the Canadair CL-84 aircraft programs, which developed flying prototypes in the late 1960s and early 1970s.

[20]U.S. Federal agencies and industry have had many years of experience in developing and testing tiltrotor technology. However, timing for commercialization depends on additional factors, making it difficult to quantify a "lead."

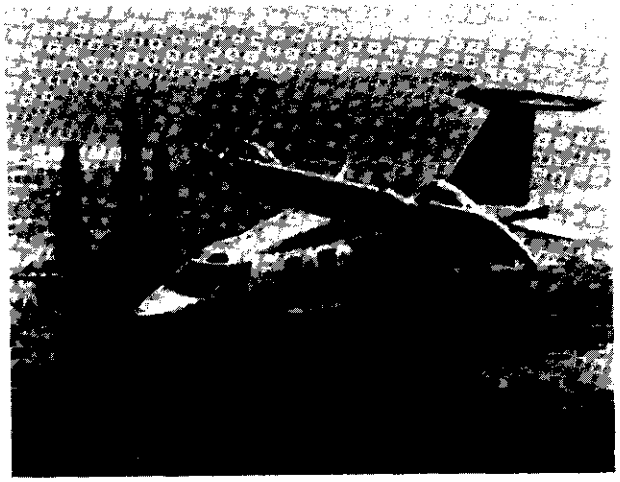


Photo credit: Ishida Aerospace Research, Inc.

The Ishida TW-68 tiltwing is designed for industrial and corporate service, and is expected to be developed and produced in Texas,

To the casual observer, a tiltwing looks and operates like a tiltrotor. However, the Ishida design, unlike the V-22, does not incorporate helicopter systems—it uses propellers, not rotors.[21] Ishida expects this simpler technology to keep tiltwing capital and maintenance costs lower than those of comparable tiltrotors.zz Since the wings tilt up for vertical flight, there is less adverse downwash on the vehicle, which helps takeoff power requirements. Unlike VTOL aircraft as large as the V-22 (roughly 40,000 pounds), the 14,000-pound TW-68 will be capable of using most existing heliports.

Many industry observers consider the tiltwing technically riskier than the tiltrotor.zs Possible tiltwing disadvantages, relative to a tiltrotor, are the added weight from mechanisms capable of tilting a full wing and engines, less vertical flight and hover capabilities, and poorer control and higher noise levels in vertical and transitional flight.[24]

Research, Development, and Demonstration Needs for Commercial Tiltrotor Systems

Commercial tiltrotor designs were considered technically feasible by all aviation experts contacted by OTA. Fundamental tiltrotor principles have been proven, and advanced flight test vehicles have flown for over a decade. However, factors critical to commercial success have yet to be demonstrated, including operational reliability and economics, exterior and interior noise levels, and community and passenger acceptance. Moreover, supporting infrastructure—vertiports, facilities, and air traffic procedures-would have to be developed and put in place to make tiltrotor commercially practical.

Commercial tiltrotor Aircraft Issues

Regardless of decisions on the V-22 program, precompetitive technology development and testing applicable to all civil tiltrotor (and most other civil VTOL aircraft) designs will be necessary prior to industry commitment to produce commercial tiltrotors. Most observers believe that the V-22 Osprey design is unacceptable for commercial operations, owing to economic and civil performance penalties inherent in meeting military requirements, although some V-22 structural and propulsion designs and components might be directly transferred to a commercial tiltrotor. Options to create a V-22 derivative for commercial transportation mostly involve design tradeoffs that will depend on market economics, certification requirements, and industry decisions, and are not discussed here.[25] Rotor noise reduction, cockpit design, and steep-angle flight systems are the main generic (R&D) needs to help make tiltrotors commercially practical.

Noise—There is common agreement that the issues related to aircraft noise in communities are major obstacles to commercial tiltrotors, since their success-

21There is no inherent reason preventing a tiltwing from using rotors or a V-22-type vehicle from using propellers, provided complementary control devices are also installed. Rotors are more complicated than propellers, enabling them to provide lift as well as power forward flight.

22David Kocurek, president, Ishida Aerospace Design, Inc., personal communication, Dec. 4, 1990.

23E.A. Fradenburgh, director, Research and Advanced Design, Sikorsky Aircraft Division, personal communication, Feb. 12,1991.

24Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, Oct.12,1990; Fradenburgh, op. cit., footnote 23; and Robert Whitehead, assistant director for Aeronautics (Rotorcraft), National Aeronautics and Space Administration, personal communication, Feb. 6,1991.

25The phase II report addressed at length commercial standards for a V-22 derivative.

Table 3-3-Noise Data and Federal Noise Standards for Aircraft

Airplane noise location	FAA noise standard[a] (EPNdB)[b]	40-seat tiltrotor noise[c] (EPNdB estimate)	40-seat airplane noise[d] (EPNdB actual)
Under takeoff path (6,500 meters from brake release)	89.0	60.0	80.8
To the side of takeoff path (450 meters from the point where noise is greatest)	94.0	74.0	86.3
Under landing approach path (2,000 meters from the landing threshold)	98.0	77.0	94.8
Rotorcraft noise location	**F/W noise standard (EPNdB)**	**40-seat tiltrotor noise (EPNdB estimate)**	**44-seat helicopter noise[e] (EPNdB actual)**
Under takeoff path (point where altitude is 150 meters)	101.6	78.0	96.2
To the side of takeoff path (150 meters from the point where noise is greatest)	102.6	84.0	97.2
Under landing approach path (point where rotorcraft altitude is 120 meters)	103.6	77.0	102.1

[a]Noise standards vary by aircraft weight; those listed here are for aircraft around 40,000 pounds. See 14 CFR 35 for further information.
[b]Effective percieved noise decibels (EPNdB) is an objective measure of noise that gives extra weight to those sound frequencies that are most annoying to the human ear. See 14 CFR 36 for further information.
[c]For a new commercial tiltrotor, not the military V-22.
dFor a DeHavilland DHC-8-1 02.
eFor a Boeing Helicopter BV-234.

SOURCE: Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study,* prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987), p. 43.

ful operation will depend on flights to destinations that currently experience little aircraft noise.[26] However, tiltrotor engineers predict that less noise will reach the ground from tiltrotors than from similarly sized helicopters or airplanes,[27] and that tiltrotor noise could be significantly reduced through technological and procedural developments.[28]

Hover and cruise performance have been emphasized at the expense of noise in the designs of most military and civilian rotorcraft, including the V-22. For example, increasing the number of rotor blades and optimizing their shape could potentially reduce noise and vibrations. However, relatively little Federal or industry research has been devoted to this effort.

tiltrotors are expected to be quieter in the cruise mode than most aircraft, and steep flight paths lessen noise levels on the ground because they decrease power required for approach, keeping tiltrotors high for as long as possible over communities, and reducing time required and ground distance covered during the descent. However, the minimum-noise flight profile to convert from cruise to landing has to be validated. Bell Helicopter Textron and NASA-Langley are collecting noise data for XV-15 takeoffs and landings, but measurements are not yet available for the larger V-22 tiltrotor.zg (Table 3-3 compares estimated tiltrotor noise with other aircraft noise levels.)

Aircraft cabin noise levels will benefit from any effort to reduce rotor noise at the source. Additionally, passive insulation, active noise suppression techniques, and rotor tip-fuselage separation are market-responsive design issues for lowering interior noise and are possible areas for more study.

Cockpit Designs and Procedures—Depending on the phase of flight, a tiltrotor will operate like a helicopter or like a conventional turboprop airplane. Cur-

26However, ambient noise from other industrial or transportation sources might be louder than tiltrotors (e.g., for vertiports built above freeways).
27Boeing Commercial Airplane Group et al., Phase II Draft Final Report, op. cit., footnote 8, p. 1-2.
28Boeing Commercial Airplane Group et al., Phase 11 Summary, pp34-36.
29Ibid., p. 35.

rently, helicopter and airplane cockpits are distinctly different, which is one reason why FAA certifies helicopter pilots separately from airplane pilots. Computerized control systems permit hybrid cockpit designs, and future airline fleet standardization and pilot career paths must be considered in developing commercial tiltrotor cockpits and procedures. Recent investigations indicate that the V-22 cockpit design, a compromise between military fixed-wing aircraft and helicopter cockpits, is not appropriate for commercial operations.[30]

NASA and FAA have conducted limited tiltrotor landing profile analyses using the V-22 flight simulator modified to reflect commercial tiltrotor characteristics. Pilots from various organizations who flew different instrument approach profiles and rated flying quality and workload[31] generally preferred 12-to 15-degree descents.[32] These simulations were limited to no-wind conditions and constant-speed descents with deceleration to vertical landing, which pilots found relatively easy to fly.[33] Curved or segmented approaches, flight profiles for short takeoffs and landings, and the effects of winds and turbulence were not examined. Moreover, all the pilots had fundamental problems with flight deck controls--each pilot moved the thrust and/or nacelle control levers the wrong way at least once during the simulated flights. Further research actively involving the airline industrt and experts in human factors[34] will be necessary for determining appropriate tiltrotor cockpit layouts and pilot certification criteria for safe operations.

Steep Angle Approach—The ability to fly optimal noise reduction profiles discussed above goes hand in hand with navigation and guidance technology development. For noise reduction, pilot workload, and safety reasons, tiltrotor operations would optimally use 12-to 15-degree approach paths. Recent simulator studies indicate that approach and descent angles up to 25 degrees might be feasible under visual flight conditions.[35] These proposed angles are significantly steeper than the approximately 3-degree glideslopes common to all precision instrument approaches used at public airports in the United States.

FAA is investigating the airspace procedures and Microwave Landing System (MLS) technology (explained later) for steep flight paths, and NASA continues to study pilot and aircraft performance in simulators. Aircraft airspeed indicators are inherently inaccurate at low speeds, so new or different instruments will have to be developed and proven to permit steep approaches during poor weather conditions. However, the basic capability for automatic helicopter approach from altitude under instrument flight conditions was demonstrated by NASA over 20 years ago.[36]

Infrastructure Issues

Commercial tiltrotor operations from urban vertiport or airport locations will require new ground facilities, ATC equipment, and procedures for terminal airspace. Most of the necessary technologies and procedures are in various stages of development by FAA but potential tiltrotor manufacturers and customers have to be confident that this new infrastructure will be validated and installed in time to support commercial operations. FAA expects its multiyear Capital Improvement Program (formerly called the National Airspace System Plan) to modernize the ATC system to expand the capacity of en route airspace over the next decade. However, if some jet shuttle passengers shift to 40-seat tiltrotors, three to five tiltrotor aircraft would enter the ATC system for each jetliner replaced.

---

30 Ibid., Phase II Summary, p. 29.

31 The Cooper-Harper scale, a standard aviation industry tool for quantifying subjective pilot opinions of aircraft handlin qualities, was used in this investigation. See G.E. Cooper and R.P. Harper, 'The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities," NASA TN D-5153, unpublished report, April 1969.

32 Boeing Commercial Airplane Group et al., Phase 11 Summary, op. cit., footnote 8, p. 42.

33 Ibid., Phase 11 Draft Final Report, p. 1-2.

34 Human factors, a discipline combining behavioral science and engineering, focuses on improving the performance of complex systems Of people and machines. Designing and operating a system so that it does not induce human error is one critical component of human factors and limiting the impact of a human error once it occurs is another aspect.

35 John F. Ward, president, Ward Associates, personal communication, June 28, 1991. However, approach angles will likely be limited to less than 25 degrees due to the aircraft's obstruction of the pilot's view of the landing zone and aircraft control limitations due to wind gusts that become a larger fraction of forward speed the steeper the approach angle becomes.

36 John F. Ward, "To Capture the Market, Put the Real 'V' in VTOL," *Vertiflite*, an American Helicopter Society Publication, vol. 37, No. 1, January/February 1991.

The safety and congestion implications of this new traffic will have to be assessed if commercial tiltrotor operations progress to that stage. Moreover, terminal facilities and airspace procedures for VTOL aircraft are not current FAA priorities, although they could be ready within the decade, given sufficient Federal, State, and local government support.

Terminal Navigation and Guidance Equipment—MLS, scheduled to become the international standard for precision instrument approaches beginning in 1998, has the capability to provide both steep-angle and curved-path descent guidance important for commercial tiltrotor operations. In addition to validating such flight procedures, MLS equipment must be developed and approved for use at small facilities such as heliports or vertiports. MLS is currently installed at two heliports for tests and evaluations, and FAA expects to publish criteria for helicopter instrument approaches for heliports with MLS equipment by early 1992.[37] In MLS, guidance signals spread out like a cone from the transmitting antenna, and the reception area narrows as the aircraft approaches for landing. Due to space limitations, the MLS azimuth antenna (which sends lateral guidance signals) will likely be located within a few hundred feet of the landing area at vertiports, possibly prohibiting some desirable flight paths. Azimuth coverage is not a problem for conventional airports where the transmitting antenna is positioned at the opposite end of the runway (possibly 2 miles away) from the approach path.

Line-of-sight obstructions in urban areas could impede conventional communication and radar surveillance systems. Satellite-based systems and LORAN,[38] two technologies used extensively by the military for long-range communication, navigation, and surveillance, are in limited, but growing, service in civilian aviation. FAA has programs scheduled over the next decade to investigate and design low-altitude ATC applications for these systems.

Airspace Procedures-Developing safe en route and terminal flight procedures is a well-established task for FAA However, bringing together new aircraft and ATC technologies while ensuring pilot and controller adaptability adds complexity and represents an important additional issue for FAA The agency modifying existing rotorcraft terminal instrument procedures (TERPS) to allow helicopters and future tiltrotors to use flight paths made possible by new avionics. Commercial tiltrotors might require more complex procedures (e.g., steeper glideslopes) than those allowed by generic rotorcraft TERPS to conduct flights at environmentally sensitive vertiports. tiltrotor proponents fear that a conservative approach by FAA to developing standards for these procedures and airspace could delay or stymie industry support for commercial tiltrotors.[39] Since a suitably equipped tiltrotor is not currently available, FAA plans to use flight simulators to develop tiltrotor TERPS, but will not certify the TERPS until they are safely demonstrated with actual aircraft.

Federal Programs for Civil tiltrotor Development

Rotorcraft-related programs in FAA, NASA and DOD help civil tiltrotor development, as do generic aviation R&D in lightweight structures and materials, engine performance, simulations, human factors, and aircraft and ATC systems. The Federal Government has spent almost $27 million over the past 5 years for civilian or dual-use tiltrotor technology programs (see table 3-4).

National Aeronautics and Space Administration—NASA, together with DOD and industry, has investigated and developed tiltrotor technology since the 1950s. The XV-15 program was a successful proof-of-concept demonstration that lead to the V-22 program. Two XV-15 aircraft are currently being used by NASA and Bell Helicopters for civil noise and terminal airspace procedures flight testing.

37 Robert Chenney, Aviation National Standards Field Office, Federal Aviation Administration, personal communication, July 24, 1991.

38 LORAN is a low-frequency radio navigation system, operated by the Coast Guard, that transmits useful signals up to 1,000 miles away. Bulky and complex LORAN receivers were designed originally for marine operations, but low-cost/low-weight signal processors now make LORAN measurements practical for aviation.

39 P.R. Thompson, Boeing Commercial Airplane Group, OTA workshop discussion, Apr. 18,1991.

Table 3-4-NASA and FAA Budgets for tiltrotor and Other Vertical Flight Technology Programs

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	5-year total
	(real year dollars in millions)					
NASA:						
tiltrotor	3.5	3.8	5.0	5.0	5.2	22.5
Rotorcraft, including tiltrotor.	22.0	23.9	21.7	24.3	25.3	117.2
Total aeronautics	332.9	398.2	442.6	512.0	591.2	2,276.9
FAA:						
tiltrotor[a]	1.9	1.0	0.7	0.4	0.4	4.5
Vertical flight RE&D[b]	2.8	4.2	4.2	4.3	5.2	20.6
Total FAA RE&D[c]	173.8	162.3	212.7	244.6	262.0	1,055.4
Total for civil tiltrotor	5.4	4.8	5.7	5.4	5.6	26.9
Total for rotorcraft/vertical flight technology	24.8	28.1	25.9	24.7	25.7	129.2

[a]Inc[udes civil tiltrotor studies, vertiport planning, and V-22 certification expenditures.
[b]Does not include vertiport planning and certification expenditures.
[c]Includes funding for facilities.

KEY: NASA= National Aeronautics and Space Administration; FAA = Federal Aviation Administration; FY = fiscal year; RE&D = research, engineering, and development.

SOURCE: National Aeronautics and Space Administration, 1991; Federal Aviation Administration, 1991; and American Association for the Advancement of Science, 1990.

Specifically for tiltrotor, NASA research focuses on improving the performance of the vehicle and integrating tiltrotors into the civil aviation system.[40] Among the current (and planned) NASA investigations are: ways to limit the adverse forces on the wings from hover downwash; reducing rotor noise and vibrations through new designs, materials, and controls; developing simulation models; studying unique tiltrotor cockpit automation and human factors issues; and exploring higher speed tiltrotor. configurations. “Additionally, NASA conducts long-range, generic R&D in aeronautics technology, such as low-weight materials and advanced propulsion technologies, that could have a direct effect on civil tiltrotor.Al NASA spends $25 million annually for rotorcraft-related R&D, with about one-fifth of that specifically for tiltrotor. (See table 3-4 again.)

Federal Aviation Administration—FAA, as the Federal agency responsible for ensuring civil aviation safety and promoting air commerce, has been involved in vertical flight certification and infrastructure development since the creation of a civil rotorcraft industry following World War II. In 1985 FAA proposed a joint study with DOD and NASA to investigate the civil potential of tiltrotors and capitalize on the ongoing military technology development. In 1988 FAA established the Civil tiltrotor Initiative to ease nonmilitary implementation of tiltrotors should demand for such service materialize. Under this program, FAA has accelerated the tiltrotor certification process by gathering early engineering and test data from the military V-22 test program and developed aircraft and operational certification criteria. FAA estimates that the V-22 could be certified for demonstration purposes by 1995 and a civil design could be approved by 1998, saving 5 to 8 years over a sequential certification process.[42]

Reflecting the level of civil rotorcraft use in the United States, FAA rotorcraft R&D programs are relatively small (see table 3-4). The $4-million average annual rotorcraft R&D expenditure over the past 5

@Robert Rosen, deputy associate administrator for Aeronautics, Exploration, and Technology, National Aeronautics and Space Administration, testimony at hearings, in U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Transportation Aviation and Materials,*Civil Tiltrotor Applications Research* (Washington, DC: U.S. Government Printing Office, July 17, 1990), p. 141.

41Ibid., pp. 141-143.

42U.S. Department of Transportation, Federal Aviation Administration, *Rotorcraft Master Plan* (Washington, DC: November 1990); and Michael Zywokarte, NYMA, Inc., personal communication, July 24,1991.

years was 2 percent of FAA's total R&D budget. FAA rotorcraft R&D focuses on infrastructure development and aircraft safety, such as terminal instrument procedures, aircraft simulation, ATC procedures, and communication, navigation, and surveillance systems. Specifically for tiltrotor, R&D funding goes to initial planning for a civil demonstration program and coordination with NASA tiltrotor technology R&D efforts. Additionally, FAA has awarded just under $3 million in Airport Improvement Program Grants for 17 vertiport planning and feasibility studies and $600,000 has been funded through the end of fiscal year 1991 to collect precertification data from the V-22 and to develop terminal airspace procedures.[43]

Market and Economic Evaluation

The market for commercial tiltrotor aircraft and service is speculative, given that neither the vehicle nor the required infrastructure exists. Since a tiltrotor will cost more per seat to purchase and operate than a similarly sized or larger conventional airplane, other factors must be important if commercial tiltrotor service is to be economical. The basis for commercial tiltrotor market potential is avoiding, and possibly relieving, air and ground congestion. There might be national competitiveness and technical readiness benefits stemming from U.S. tiltrotor technology and industrial base development, although such benefits are not analyzed in this report.

The value of commercial tiltrotor passenger or freight service relative to other air travel options lies mainly in two areas: 1) improving door-to-door trip times for passengers (or cargo) by circumventing ground and air congestion, and 2) expanding the capacity and reducing the runway congestion at the busiest airports by permitting some short-haul traffic (trips of less than 500 miles) to shift to tiltrotors, thus freeing runway space for larger aircraft. Whether these benefits are sufficient for industry to produce commercial tiltrotors and for airlines to operate them is unclear.

Public data are sparse on door-to-door travel and passenger perceptions of ground access costs and value of time, making demand projections difficult. Another uncertainty is the willingness of hub feed commuter airlines, most of which are affiliated with major air carriers, to switch to tiltrotors without new Federal and local government policies. Moreover, how much traffic could be diverted from generally lower cost automobile trips and other nonair travel modes or otherwise be generated by the time-saving potential of tiltrotor is not well understood. Hence, only airline traffic between urban areas is considered as the initial market base for commercial tiltrotors.Q'l

Crucial to commercial tiltrotor service are safe and reliable aircraft, a suitable infrastructure, and willing airline operators. To focus on the markets and economics of commercial tiltrotors, OTA has assumed that the infrastructure could be in place and other possible institutional hurdles could be overcome. (Institutional factors that could impede a commercial tiltrotor system are discussed in the next section.) Much of the background data on tiltrotor economics and markets used in this section comes from the NASA/FAA Phase 11 study. According to that study, if a market-responsive tiltrotor and infrastructure were available today, intercity passenger service would be viable **in certain markets.** However, further analysis is needed to determine whether there is enough demand to justify producing commercial tiltrotors in the next decade. Moreover, a better understanding is needed about the increases in capacity and the degree of congestion relief to be realized through commercial tiltrotor operations and about what public policy support, if any, might be necessary. The primary reason FAA is studying tiltrotor technology is to reduce air traffic delays.[45]

Tiltrotor Economics

tiltrotors will not offer improved cost airspeed, trip frequency, or comfort over existing aircraft serving urban airports; their value depends on overcoming runway and road congestion.[46] For intercity service, a

43Joseph M. Del Balzo, executive director for system Development, Federal Aviation Administration, personal communication, June 10,1991.
44George Unger, National Aeronautics and Space Administration, OTA workshop discussion, Apr. 18,1991.
45Michael Zywokarte, NYMA, Inc., personal communication, July 2,1991.
46Studies indicate that tiltrotors might offer better and more economical service in regions where transportation is difficult, such as Alaska and the Caribbean according to Ted Lane, Thomas/Lane & Associate, personal communication, June 28, 1991.

tiltrotor system design would use a distributed network of terminals (as opposed to the more centralized network of existing hub airports) that could allow shorter and quicker ground trips for air travelers. **Other actions to reduce current and projected transportation problems, especially airport congestion, might dilute many of the advantages cited for commercial tiltrotor.** For example, a downturn in the economy, use of larger aircraft, or better management of aviation infrastructure might lessen the pressure on the busiest airports. Moreover, the accuracy of FAA airport congestion forecasts is open to question—projections are based on limited data and do not account for possible changes in air carrier operating practices if the delay costs become too burdensome (see forecasting section in chapter 2).

However, if airport congestion grows over the next decade, there will be few acceptable public options to ameliorate it. Adding new airport capacity will be difficult-communities oppose most plans for new runways and airports, and advanced technologies to squeeze more flights into airports will be slow to come online and will produce marginal improvements at best.[47] Demand management mechanisms, such as runway differential pricing, generate heated protests from users and create issues of social and economic equity that are hard to resolve.[48]

Costs To Build and Operate Commercial tiltrotors

For a given level of technology, the cost to build and operate an aircraft depends on its payload capacity and design range. Selected commercial tiltrotor designs from 8 to 75 seats with ranges up to 600 miles were considered in the earlier Phase I study.@ Cost data for commuter airline turboprop airplanes were used to gauge commercial tiltrotor economic estimates, since the size, en route performance, and the nature of airline operations for tiltrotors are assumed to be similar to those for turboprops. The following assumptions were made in the Phase II study:

- Military V-22 production and operating costs are not analogous to commercial tiltrotor costs, owing to differences in mission requirements, materials, military procurement rules, and production rates.
- Only a small percentage of tiltrotor flight time will be in the helicopter mode (e.g., vertical flight would account for 2 percent of a 200-mile trip). This is important because maintenance and fuel costs climb with increased use of vertical flight.
- Generic turboprop and jet aircraft cost data, derived from actual airline and manufacturer figures, are used to estimate and compare tiltrotor economics.
- A commercial tiltrotor would cost 40 to 45 percent more to build than would a turboprop with equivalent size, range, and overall quality.

A 39-seat tiltrotor was found to be a good compromise size for the flight frequency and passenger volumes required for the commercial markets studied by the Phase II team. Such an aircraft is similar in size to the V-22 ***Osprey*** and might benefit from some common technology and components. However, changes in market factors and closer analysis of potential demand might indicate a different optimal tiltrotor configuration.

The Phase II study team analyzed the costs to build, maintain, and fly a commercial tiltrotor. Some of the findings are provided in table 3-5, which compares economic figures for tiltrotor, turboprop, and jetliner aircraft. For flights longer than around 100 miles, tiltrotors would be more expensive than equivalent turboprop for an airline to operate. However, tiltrotors flying from vertiports could offer significant savings in time and ground transportation costs for passengers who normally travel through major airports, possibly making tiltrotors competitive in certain markets.

If Ishida tiltwings or other high-speed VTOL aircraft go into production, their effect on the airspace system and the demand for commercial tiltrotor service will have to be factored into tiltrotor forecasts. Detailed cost data are not yet publicly available, but

47 U.S. Congress, office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 84.

48 1 bid., p. 85.

49 tiltrotor and conventional turboprop aircraft with 8,19,31,39,52, and 75 seats were analyzed in the Phase I study.

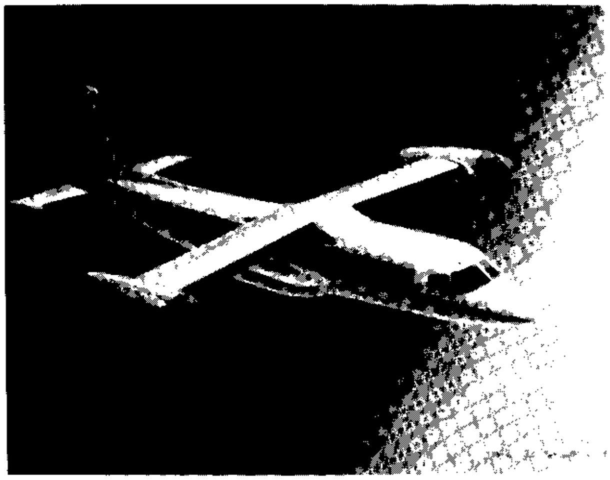


Photo credit: Bell Helicopter Textron, Inc.

Although similar in size to the V-22, a 39-seat commercial tiltrotor (shown in this artist's conception) would incorporate different design features, such as a new fuselage.

the Ishida tiltwing aircraft, designed primarily for the corporate transport market, might be competitive with commercial tiltrotors on certain commercial routes. Although a 14-seat tiltwing will likely have higher seat-mile Costs[50] than a 39-seat tiltrotor, it is designed to fly at least as fast and as far, use smaller landing areas, and perhaps be more economical for high-frequency service on routes with too few passengers for 39-seat tiltrotors.

tiltrotor Service Scenarios

The Phase 11 team analyzed various types of service for civil tiltrotors and determined that routes of 100 to 500 miles with high levels of ground and/or air congestion at one or both ends offered the greatest potential for commercial tiltrotors. The prime markets are point-to-point trips between urban areas, including city center to city center, and commuter connections to congested hub airports. Service to small cities or uncontested hubs using 40-seat tiltrotors is not considered economically viable.

Point-to-Point Service Between Urban Areas

Travel corridors characterized by strong business travel, existing air shuttle service, and difficult ground access to major airports are leading candidates for point-to-point tiltrotor service. U.S. air travel routes with these attributes include Washington-New York-Boston, Dallas-Houston, and Los Angeles-San Francisco.

On these routes, tiltrotors would compete with larger jetliners averaging 130 seats per aircraft.[51] The value of reduced time and access costs for shorter ground trips to and from strategically located vertiports is especially critical for penetrating these airline markets, since the cost per seat for the air portion of the trip would be significantly higher for the tiltrotor than for a jetliner (see table 3-5 again).[52] Pan Am and Trump shuttles carry approximately 3.8 million passengers per year on New York-Washington and New York-Boston routes, or about three-quarters of the air travelers in these markets.

The Phase 11 team analyzed a hypothetical commercial tiltrotor system for the NEC and devised schedules, computed travel times, identified potential locations for vertiports, and estimated the number of passengers diverted from conventional airplanes and the number of additional flights using the airspace. The study team assumed that shorter trip times and resulting lower ground access costs would compensate for the higher operating costs and consequent ticket price for tiltrotorservice and that passengers would consider freed-wing and tiltrotor service economically equivalent: On this basis, using the Boeing Market Share Model,[53] the team calculated passenger demand based on service frequency and trip time.[54] Flight schedules and total aircraft inventory needs (based on fuel capacity, turnaround times, and other operating requirements) were estimated. Under these assumptions, the study found that commercial tiltrotors would capture 94 percent of the intra-Northeast Corridor market.

50 Other things being equal, larger aircraft are more economical per seat-mile than smaller aircraf Tiltwings are projected to cost about 15 to 20 pereent more to operate than an equivalent turboprop. This is similar to tiltrotor cost estimates.

51 Boeing Commercial Airplane Group et al., Phase II Draft Final Report, op. cit., footnote 8, p. 3-92.

52 The cost per passenger will depend, in part, on the percentage of seats that can be filled.

53 A proprietary simulation model for fleet planning developed by Boeing Commercial Airplane Co.

54 It is difficult to calculate market Share when both cost and travel time are variables.

Table 3-5-Comparative Economic Data for Commercial tiltrotors Operating in the Northeast Corridor

Categories	tiltrotor (39-seats)	Turboprop (39-seats)	B737-300 (128-seats)
	Operating costs[a] in 1989 dollars for 230-mile trip ($ per seat-mile)		
Aircraft capital Costs[b]	0.067	0.054	0.038
Maintenance costs	0.048	0.036	0.014
Fuel Costs[c]	0.019	0.011	0.011
Total aircraft costs[d]	0.203	0.172	0.122
	Travel times[e] for 230-mile trip (hours: minutes)		
Ground travel	0:36	1:34	1:34
Airport terminal	0:30	0:45	0:45
Onboard aircraft	0:50	1:06	0:54
Total trip time	1:56	3:25	3:13
	Ground and air travel costs for 230-mile trip (per passenger)		
Taxi fare[f]	$12.80	$33.10	$33.10
Flight Costs[g]	71.82	61.02	43.09
Total travel costs	84.62	94.12	76.19

[a]Assumes passengers occupy 65 percent of seats.

[b]Depreciation, financing, and insurance costs.

[c]At $0.60 per gallon.

[d]Total costs for each aircraft type, which include flight crew, passenger service, landing fee, and ground handling expenses, reflect commuter airline wage scales and service levels, which are generally less than those for major airlines.

[e]Assumes Northeast Corridor ground travel and airport conditions; turboprop and jetliner ground and airport terminal times are for major airports.

[f]Typical trips to and from Northeast Corridor airports used for turboprop and jetliner calculations; trips to and from well-situated vertiports used for tiltrotor taxi fare.

[g]Breakeven costs to airline with 65 percent of passenger seats occupied; ultimate ticket price could vary considerably.

SOURCE: Office of Technology Assessment, 1991, based on Boeing Commercial Airplane Group et al., Civil Tiltrotor *Missions and Applications Phase II: The Commercial Passenger Market,* Draft Final Report, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

While the Phase II NEC analysis is an important step for understanding tiltrotor effects on ATC and potential passenger demand, further scrutiny using representative market conditions is needed to provide credible support for industry or public policy decisions regarding commercial tiltrotors. The Phase II study compared tiltrotors with turboprop aircraft only and did not include the monetary value of the time saved by tiltrotor passengers in its demand analysis.[55] It is reasonable that taxi fares and airline ticket costs could be equivalent for these two types of aircraft. However, only 10 to 15 percent of airline passengers who travel between the major NEC airports do so in commuter aircraft.[56] Jetliners, the dominant mode, cost about one-third less per seat to operate than commuters along NEC routes.[57] The ground access and flight costs[58] for a tiltrotor passenger would be 11 percent higher than if the same journey were taken via major airports served by jetliners (see table 3-5 again). A **tiltrotor network would still offer significant savings in total trip time relative to jet service, but it is unclear what size passenger market tiltrotors would attract. The** jet shuttle market might be difficult to penetrate, but tiltrotors could supplement shuttle flights with new services and absorb extra traffic, if airport congestion becomes a constraint.

55 Estimating the value of time is admittedly difficult.

56 OTA calculations based on *Official Airline Guide* data for April 1991.

57 From phase II data comparing B737-300 and generic 39-seat turboprop over a 230-mile distance in revenue passenger service.

58 Total cost to the airline to provide the seat, not the ticket price paid by the passenger.

Revised tiltrotor demand estimates could lead to different conclusions regarding optimal aircraft size and vertiport locations. FAA is conducting independent economic and market evaluations using lower overall market projections and has a small study under way comparing commercial tiltrotors with the Pan Am and Trump shuttles, but the results are not yet publicly available.[59]

Replacing Commuter Airplanes as Airport Hub Feeders

Air service from small cities to congested or slot-constrained hub airports is another potential market for commercial tiltrotors. Commuter turboprop airplanes provide most of this feeder service, and replacing some of them with similarly sized tiltrotors could free up valuable landing slots for more productive, long-haul aircraft while still providing vital air connections for small communities. The potential passenger capacity gains for NEC airports are substantial. At Boston, for example, commuter airlines use 30 percent of the landing slots but carry only 5 percent of the airport's passengers.[60] Since tiltrotors cost more to operate and offer no significant time savings over commuter turboprop airplanes if both fly from conventional airports, the economic viability of tiltrotors in this market depends on balancing higher tiltrotor costs with the increased revenues and benefits from runway slots that could be used by more people in larger aircraft. Presently, there is no public policy encouraging efficient use of runway slots or enabling airlines to "capture" the benefits of congestion relief.

Maintaining (and increasing) market share is important to airlines. Established air carriers and their commuter airline partners have little incentive to free up runway slots if other airlines get to use them. With the exception of four airports—Chicago O'Hare, New York Kennedy, New York LaGuardia, and Washington National—landing and takeoff slots are first come/first serve for any aircraft operator. At the four "slot-controlled" airports, landing and takeoff quotas have been established by FAA for three user classes—air carriers, commuters, and general aviation. Federal regulations[61] prohibit the transfer of slots between user classes (e.g., an air carrier cannot use a commuter slot). Moreover, air carriers would not always be able to take advantage of a commuter slot even if one opened up, since at many airports turboprop aircraft use runways too short for jetliners.[62]

Two-thirds of airline delays occur during bad weather,[63] when short runways are usually not used. With current technology and procedures, most airports can safely operate one or two runways only, when atmospheric conditions, such as low clouds, impair pilot and tower controller visibility. This reduces by 50 percent or more the number of aircraft that can takeoff and land relative to clear-weather capacity. Under these circumstances, commuters, private aircraft, and jetliners alike must use the same runways, further complicating the already congested traffic flow. tiltrotor service could clearly increase capacity at some busy airports, such as New York's LaGuardia, that do not have separate runways available for commuter turboprop.

The Phase II study investigated the economics of replacing some hub feed commuter flights to NEC airports with tiltrotor service and calculated the number of slots freed and the required cross-subsidy per slot to cover the tiltrotor's higher costs. The methodology for this analysis was to calculate the cost difference to provide the same number of seats annually by 39-seat tiltrotors and 31-seat turboprops.[64] The slot revenue required to support tiltrotor service based on these calculations[65] ranged from over $100 per day per

59 Michael Zywokarte, NYMA, Inc., personal communication, July 22,1991.

60 Massachusetts Port Authority, "MassPort's Program for Airport Capacity Efficiency," unpublished report, Dec. 11,1987.

61 14 CFR 93, Subpart K.

62 The Federal Aviation Administration has proposed amending slot rules to permit regional jets (as large as 110 seats) to use a limited number of commuter turboprop slots at Chicago O'Hare. See 56 *Federal Register 21404* (May 8, 1991) for further details.

63 U.S. Department of Transportation, Federal Aviation Administration, *1990-91 Aviation System Capacity Plan*, DOT/FAA/SC-90-l (Washington, DC: September 1990), p. 1-11.

64 The 31-seat generic turboprop in the phase II database approximates the 30-seat overall average for the Northeast Corridor markets analyzed.

65 Assumes that tiltrotor purchase price is 50 percent higher than an equivalent turboprop, or $300,000 per seat, and that tiltrotors would replace all turboprops flying the busiest (top 50 percent) routes to the hub airport.

runway slot for Washington, DC, to virtually nothing for Philadelphia.[66]

A limitation of this Phase II analysis is that it does not address the economics of replacing each turboprop flight with a tiltrotor. For example, in the Boston commuter market, where average aircraft size is 24 seats, small communities would lose 38 percent of their flights to Logan Airport under the equivalent seat scenario. For Boston, the cross-subsidy would have to beat least seven times higher than the figures published in the Phase II report if equal frequency service is to be provided by 39-seat tiltrotors.GT Using tiltrotors closer to the size of the aircraft that they replace would be somewhat better economically if equivalent schedules are to be maintained. For the Washington, DC, market, where commuter flights average 39 seats, it would cost $470 extra to replace a turboprop round trip with tiltrotor service (thereby freeing one slot).[68] (The landing fee for a 150-seat aircraft at Washington National Airport is about one-third[69] this amount.)

Domestic and Worldwide Potential Market

Three-quarters of all scheduled airline flights worldwide are for travel less than 500 miles, making them potential candidates for replacement by tiltrotors. Using ***Official Airline Guide*** schedules and Boeing Commercial Airplane Co. forecast data, the Phase II study predicted potential demand for tiltrotor aircraft by examining the traffic characteristics of the busiest routes, considering only those routes where tiltrotor economics could be favorable. City pairs with lower density traffic, less ground congestion, or routes longer than 300 miles were de-emphasized, and small markets, hub feeder flights, and airlines offering few flights per week were excluded. Other economic assumptions used in the NEC analysis were applied in the global market assessment. The Phase 11 study identified **220 candidate city** pairs that could use over 2,600 commercial 40-seat tiltrotors by the end of the decade if a suitable infrastructure were in place (see table 3-6). Approximately one-half of this potential demand lies outside the United States. Further analysis is necessary to account for direct economic competition between jetliners and tiltrotors, since only turboprops were the reference base. Jets provide about 45 percent of the passenger capacity for trips under 500 miles.

For the year 2000, Ishida projects a market for about 750 high-speed VTOL aircraft, and Eurofar sees demand for 30-seat commercial tiltrotors,TO with both groups anticipating a similar 50-50 split between the United States and the rest of the world in demand for their high-speed VTOL aircraft.[71] These estimates indicate that U.S. market conditions (including infrastructure policy decisions) could determine tiltrotor (and other high-speed VTOL) characteristics. If the magnitude of worldwide commercial tiltrotor demand

Table 3-6—Market Potential for 40-Seat Commercial tiltrotor in Year 2000

Region	City pairs	Number of aircraft
North America[a]	117	1,268
Europe	57	615
Japan	26	501
Oceania[b]	20	239
Total	220	2,623

[a]Seven areas: 1) Northeast Corridor; 2) Southeast, based in Atlanta; 3) Midwest, based in Chicago; 4) SoUth-central, based in Dallas-Fort Worth; 5) Southwest, centered in San Francisco, Los Angeles, San Diego, and Phoenix; 6) Northwest, based in Seattle; and 7) Hawaiian Islands.
[b]Western pacific Rim countries, excluding Japan.

SOURCE: Boeing Commercial Airplane Group et al., *Civi/ 7i/trotor Missions and Applications Phase //: The Commercial Passenger Market,* Summary, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASACR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

66 Tiltrotors compare so favorably with turboprop in the Philadelphia market because the average trip distance is small, around 124 miles. Tiltrotors become more economica than conventional airplanes for trip distances under 100 miles *or so.* However, helicopters perform better than tiltrotors if distances are reduced further.

67 This estimate is based on the cost difference, accounting for different passenger load factors, between flying 39-seat tiltrotors and 31-seat turboprops on the Boston routes. Data source is the Phase 11 report. The cost difference would be substantially greater between 39-seat tiltrotors and the 24-seat average aircraft actually flown in the Boston market.

68 The phase II study, by using the 31-seat turboprop as the reference base for the Washington, DC, market analysis, underestimates the tiltrotor cost difference, since the smaller aircraft would be more expensive to use on Washington, DC, routes than would 39-seat turboprops.

@The landing fee for air carriers at Washington National is $1.04 per 1,000 pounds of landing weight, or around $160 for a B-727.

70 We assume that all these markets overlap, and the figures are therefore not additive.

71 Kocurek, op. cit., footnote 22; and Joseph M. Del Balzo, executive director for System Development, Federal Aviation Administration, testimony at hearings, in House Committee on Science, Space, and Technology, op. cit., footnote 40, p. 157.

holds true, the export value of U.S.-manufactured tiltrotors could exceed $15 billion in 2000.[72]

Institutional Framework

Congressional and other public interest in tiltrotors has focused primarily on the vehicle technology and its military role. Whether potential benefits of proposed tiltrotor service, such as congestion relief, are realized will depend on the institutional framework and the air and ground infrastructure within which tiltrotor must be developed and operated. Marketing skills and political and industrial coalitions will be essential for getting the technology out of the workshop. A host of challenges, many of them nontechnical, face future tiltrotor intercity systems, including: community acceptance of facilities and operations; properly situated terminals with adequate ground connections; suitable ATC equipment and procedures; people and organizations willing and able to plan, design, build, operate, maintain, and manage the system; a regulatory framework to ensure that the system is developed and run in a safe, environmentally acceptable, and economically fair manner; and available financing to support the system (see table 3-7).

tiltrotor Safety Oversight

FAA which has regulatory authority for all aspects of civil aviation safety, would be responsible for certifying tiltrotor vehicles, operations, procedures, personnel, and landing facilities. Because it has worked closely with DOD to collect data from the V-22 flight test program, FAA is well positioned to provide safety certification services if industry proceeds with a civil tiltrotor program. FAA's Rotorcraft Directorate in Fort Worth, Texas, has developed airworthiness standards[73] that apply to other powered-lift vehicles as well. FAA methodology for developing helicopter en route and terminal airspace procedures is applicable to tiltrotor, and some existing helicopter routes might be suitable for tiltrotors. A vertiport design guide to aid local planners has recently been released by FAA[74] If put into common carrier service, tiltrotors will be subject to the same or equivalent operating regulations as larger airliners.[75]

While additional flight testing and analyses are needed to establish specific requirements for tiltrotors (e.g., pilot training, cockpit instrumentation, maintenance standards), neither the tiltrotor design nor FAA's regulatory framework should significantly impede the certification of a civil tiltrotor. However, some tiltrotor operations and procedures cannot be certified until appropriate ATC technologies are developed and approved and actual flight test aircraft are available.

Environmental Issues and Community Acceptance

The feasibility of establishing vertiports depends on the balance of environmental concerns and perceptions, the state of local transportation systems, and the potential for economic development. Aircraft noise is a serious problem for airport operators and airlines, and is the leading environmental issue for tiltrotor. Community groups fighting to restrict airport operations because of noise concerns have limited airport development across the country. Interviews conducted with public officials in 13 U.S. cities indicated that vertiports could be located and tiltrotors operated in their urban areas if noise levels are as low as projected.[76] New public heliports have opened in recent years or are being built in Indianapolis, Manhattan, Portland (Oregon), and Dallas,[77] but helicopter operations are not welcome in most communities, and few scheduled helicopter airlines have ever been profitable (see box 3-C).

While the intensity of sounds can be measured precisely, determining what constitutes objectionable

72 Assuming a $300,000 per-seat purchase price.

73 U.S. Department of Transportation, Federal Aviation Administration, "Interim Airworthiness Criteria: powered-Lift Transport Category Aircraft," unpublished report, July 198S.

74 U.S. Department of Transportation, Federal Aviation Administration, *Vertiport Design*, Advisory Circular 150/5390-3 (Washington, DC: May 31, 1991).

75 14 CFR 121 o, Comparable regulations would apply if tiltrotors have more than 30 passenger-seats.

76 Robert L. Neir, market research manager, Boeing Commercial Airplane Group, personal communication, Feb. 27, 1991.

77 Zywokarte, op. cit., footnote 42.

Table 3-7—tiltrotor System Issues

Component	Issues	Comments
tiltrotor aircraft	V-22 program status; need for a civil demonstration program; commercial market size.	Administration has attempted to end the V-22 in fiscal years 1990 and 1991; civil demonstration program proposed in the NASA/FAA Phase II study.
Vertiport	Federal airport capital grant policy for vertiports is unclear; sites that are acceptable to communities and are operationally suitable depend in part on new technologies and flight procedures.	Waterfront, industrial, underused small airports, and nonurban interstate sites appear plausible; residential and central business district locations doubtful; multiple-use facilities could help limit development costs for vertiport portion.
ATC system	Appropriate technology, procedures, and manpower needed to gain benefits of tiltrotor flight capabilities. Large increase in the number of daily en route flights possible.	Rotorcraft have never been well integrated into the airspace system; no public heliport in the United States now has precision instrument landing capabilitiesessential for scheduled passenger operations. En route operations by tiltrotors are no different than those by conventional aircraft, and FAA has programs under way to enhance the capabilities of en route airspace.
Regulatory oversight	Cockpit design and pilot training; noise standards for tiltrotor and vertiports.	V-22 flight test data are being analyzed by FAA; airworthiness criteria for tiltrotor-type aircraft are published (in interim form); vertiport planning guidelines are available; airspace procedures are being studied in simulators.
Potential operators	Major airlines have not embraced tiltrotor. Are potential tiltrotor system benefits realizable for an existing or entrepreneur airline?	Lack of aircraft and infrastructure has dampened airline interest; airlines will not voluntarily free up airport capacity for competitors; scheduled passenger helicopter service, in some respects comparable to tiltrotor, is virtually nonexistent in the United States.
Local communities	Noise, safety of overflights, and potential increases in surface traffic are key community concerns.	With appropriate airspace procedures, vertiports and their operations could be isolated from residential areas; some planning analyses are under way (e.g., FAA vertiport studies).
Passengers	Would potential passengers recognize cost and service benefits of tiltrotors?	Safety and service levels at least comparable to large commuter operations required; total direct ground and air costs to passengers could be less than current air options in certain markets. How do travelers value ground access time and cost?
Financiers and investors	What assurances are needed for non-Federal investors in tiltrotor technology and what is the Federal role?	Public and private investment in the United States limited primarily to planning and design studies to date; new heliports are being designed to vertiport standards; no commitment to develop commercial tiltrotor in the United States.

KEY: NASA = National Aeronautics and Space Administration; FAA= Federal Aviation Administration; ATC = air traffic control.

SOURCE: Office of Technology Assessment, 1991.

noise is more subjective. FAA sets noise standards for aircraft designs, commonly referred to as Stage 1, 2, and 3 rules,[78] and for airport planning.[79] While differences in local conditions and jurisdiction: factors have made establishing a more definitive Federal standard for airport noise difficult, Stage 1 aircraft are already banned, and all Stage 2 aircraft are prohibited after December 31, 2000.[80] Rotorcraft are not presently covered by these "stage" rules, but industry proponents claim a civil tiltrotor would be able to meet Stage 3 requirements.

Although civil tiltrotors might be less noisy on commercial flight paths than helicopters and most fiied-

[78] 14 CFR 36.

[79] 14 CFR 150.

[80] *Congressional Record,* Oct. 16,1990, p. 12535.

Box 3-C-Current Helicopter System Issues

Since helicopters and tiltrotors perform comparably at or near landing facilities, a look at helicopter airline operations might illuminate potential tiltrotor system obstacles. A great many helicopters, trained pilots, and public and private heliports exist in the United States, and helicopters are used extensively in situations where no other aircraft could operate--emergency medical services, police operations, search and rescue missions, and offshore oil rig support, to name a few. Scheduled helicopter service from Chicago, New York, and Los Angeles airports was subsidized by the Federal Government from 1954 through 1966, and each of the helicopter airlines operating during those years went out of business by the late 1970s. During the past decade, a few helicopter airlines established interline agreements with major airlines, which helped defray the cost of these connecting flights for their passengers. None of these airlines is currently operating.[1] Although operating costs are much higher than those of airplanes, economics alone has not kept helicopter passenger service on the ground.

Lack of a "helicopter friendly" infrastructure is the main complaint of rotorcraft operators. Few public heliports exist, and none are equipped with precision landing guidance systems that are essential for all-weather scheduled operations. When helicopters use conventional airports, air traffic controllers usually direct them along airplane flight paths (which are fatal to any profit margin the helicopter had), even though helicopter-specific routes are often available. Air traffic controllers are inherently conservative and are most secure with airplane procedures. Moreover, during busy periods, controllers may be able to monitor only fried-wing routes safely.[2]

Noise, on the ground and in the cabin, has weakened public acceptance of helicopter service. However, some noise problems are due to flight paths dictated by air traffic control (ATC), and current technological know-how could reduce noise (interior and exterior) and vibrations and improve ATC capabilities. rotorcraft manufacturers and the Federal Aviation Administration, with most of its resources and expertise devoted to fixed-wing aircraft, have not strongly promoted passenger helicopter service.

[1] HubExpress, one of the few scheduled helicopter services in the United States, recently went out of business.

[2] Joel Hicks, director for Safety, Technology, and Training, National&Traffic Controllers Association, personal communication, Mar. 22,1991.

wing aircraft, they may not be quiet enough to satisfy those communities where vertiports are most likely to be located to capture the largest possible market share. FAA actions to reroute aircraft over New Jersey caused an uproar from communities that previously had few overflights, even though average sound intensity from these flights was less than that from normal conversational tones. Moreover, most communities that might accept tiltrotor vertiports would turn them down if louder helicopter operations were permitted.[81] On the other hand, vertiport operators would probably welcome the additional revenue from helicopter flights. Technically, helicopters could be designed and operated to be less noisy than is common now. Presently, there are no Federal noise standards specifically for heliports or vertiports. Airport noise compatibility planning guidelines (14 CFR 150) are now used for heliports.[82]

The environmental impact of building (as opposed to operating) a vertiport should be relatively minor, especially compared with airport and other transportation infrastructure construction, owing to minimal land requirements (up to 5 acres). Also, the air quality

81 Boeing Commercial Airplane Group et al., Phase 11 Summary, op. cit., footnote 8, p. 11.

82 The definition of "airport" in 14 CFR 150.7 specifically excluded heliports until1989.

impact of tiltrotor engine emissions should be relatively small. In the Los Angeles basin, aircraft exhaust and fueling emissions from all aviation operations contribute about 1 percent of the total volatile organic compounds. FAA and the Environmental Protection Agency (EPA) are addressing these air quality issues by requiring that new jet engines reduce organic compounds emissions by 60 to 90 percent. EPA is considering regulations requiring vapor recovery systems for aircraft fueling,[83] and civil tiltrotors would be required to meet these standards.

Role of the Airlines

Commercial tiltrotor passenger service in the United States, if practical, will likely be controlled by major air carriers rather than by new tiltrotor airlines. Potential tiltrotor routes are now dominated by jetliner shuttle flights or commuter airlines associated with the major carriers. While tiltrotors could offer a way to avoid the shortage of airport gates and runway slots that hinder access into the largest intercity air travel markets, high purchase and operating costs and necessary technical sophistication could put tiltrotors out of the reach of financially strapped startup airlines. Moreover, the formidable marketing power of major airlines-extensive route networks, frequent flyer programs, travel agent commissions, and computer reservation and ticket pricing databases—has become essential in competing for air travelers. Most commuter airlines now operate under the name of a major carrier, who often dictates the smaller airline's schedules, airport gates, and advertising.

U.S. airlines have expressed little interest in commercial tiltrotors. Beset with financial losses in recent years, a number of airlines concentrate on day-to-day survival. tiltrotor aircraft, which will cost more to purchase and operate than conventional airplanes and will require new infrastructure, turn few heads in airline management. Before an airline will consider placing orders for a commercial tiltrotor, it must be convinced that the aircraft is operationally reliable and economically viable. Data from military production and operation of the V-22 and a civil tiltrotor demonstration program would get airlines' attention regarding tiltrotor technical performance. Proven community acceptance and a public commitment to install the infrastructure would also be crucial.

Establishing that commercial tiltrotor has more than a niche market potential is another matter. Tiltrotor costs and public policies regarding airport congestion combine to offer few incentives for airlines to introduce tiltrotor service. The potential benefits of commercial tiltrotors would not go to an airline's balance sheet, but would instead go mostly to the tiltrotor passengers, who would get quicker and easier trips. The general public would also receive expanded aviation system capacity for relatively little infrastructure investment. The tiltrotor's advantage to individual airlines is unclear. Data from the Phase II report indicate that beating the profitability of jetliner shuttles, which in most cases can switch to larger airplanes as demand grows, is questionable (see table 3-5 again). Furthermore, a recent analysis indicates that the primary air carriers in the NEC lost $11 million in operations there in 1990.[84] The need and value of freed runway slots has not been demonstrated, and there is no policy to ensure that an airline could take advantage of the runway slots it opens through tiltrotor service.

Financing

The Federal Government has spent over $2.5 billion for XV-15 and V-22 development programs,[85] and private industry has invested another $200 million to $300 million of its discretionary funds on tiltrotor technology.[86] Around $1 billion to $1.5 billion more will be necessary for U.S. industry to develop, certify, and produce a commercial tiltrotor,sT and like other U.S. commercial aircraft programs, most of this funding would have to come from private sources. So far, private industry has not pledged to develop a commercial tiltrotor.

83Nicholas P. Krull, office of Environment and Energy, Federal Aviation Administration, personal communication, July 31, 1990.

84John P. O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28,1991.

85Boeing Commercial Airplane Group et al., Phase 11 Summary, op. cit., footnote 8, p. 4.

86Federal Aviation Administration, Research, Engineering and Development Advisory Committee, tiltrotor Technology Subcommittee, *Report* (Washington, DC: June 26, 1990), p. 12.

87Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, Feb. 6, 1991.

The five European governments that sponsor Eurofar have spent $30 million[88] on commercial tiltrotor studies during the past 3 years and are developing a technology base and considering building a tiltrotor demonstrator over the next 5 years. The figures for the TW-68 tiltwing program, financed to date only by Ishida Corporation, are not publicly available. However, Ishida officials claim funding is assured through prototype flight testing.

Without continued production of the V-22 or additional public funding to develop and demonstrate civil tiltrotor technology, a U.S. company will not build a commercial tiltrotor this decade. A recurring question in debates on Federal participation in civil tiltrotor programs is "if the technology is such a good idea, why doesn't U.S. industry fund it without public support." One group that looked into this question concluded that the reasons are: 1) a lack of long-term capital support in the United States; 2) insufficient or nonexisting infrastructure; and 3) no confidence or commitment from potential operators without operational test data.[89]

The Phase 11 study recommends creating a 4-year program, costing roughly $250 million, to develop further the tiltrotor vehicle and infrastructure technologies and to assess the feasibility and benefits of a commercial tiltrotor system.[90] The centerpiece of the program is a series of operational demonstrations using XV-15 and V-22 tiltrotors. Commercial product development or production is not proposed.

Federal support for VTOL infrastructure is continuing. Federal Airport Improvement Program grants are available for planning and building landing facilities that relieve traffic from air carrier airports (as would be expected at vertiports). FAA has provided about $3 million to local authorities for vertiport planning studies, and it is expected that construction grants will be available for vertiports. However, FAA policy is not yet clear on vertiport construction. Expected Federal capital grants for the first public heliport designed to accommodate 40,000-pound tiltrotors were tied up within FAA because no manufacturer has committed to producing commercial tiltrotors, and the need for vertiports has not yet been (officially) established.[91] However, a portion of the earlier assigned Airport Improvement Program funds was awarded in fiscal year 1991, and FAA plans to issue additional funds in fiscal years 1992 and 1993 for the Dallas Convention Center heliport.[92]

Findings and Conclusions

For tiltrotors to succeed commercially, the congestion and delays that have increasingly plagued roads and airports during the past decade must continue to grow. Airlines and their customers will demand tiltrotors (which cost more to build and operate than competing fixed-wing aircraft) only if the expense of ground and air congestion becomes too severe. While most aviation forecasts project that passenger demand will grow faster than airport capacity, future congestion levels are difficult to assess. FAA predicts most increases in aircraft flights will occur at hub airports, where airline scheduling strategies rather than passenger demand determine how crowded the runways and ramps become. Moreover, the same airline philosophies, community concerns about noise, and public policies that have hampered other means of overcoming air travel delays will affect tiltrotor use.

Although further research and FAA certification approval would be needed, the technical feasibility of safely carrying passengers with tiltrotors is not seriously in doubt, and tiltrotors could offer one way to avoid clogged highways and overburdened runways and might help expand the capacity of busy hub airports. High-density urban-to-urban routes and feeder service to congested hubs are the most promising markets for commercial tiltrotors. A tiltrotor network would offer significant time savings relative to jet service for trips under 500 miles, but it is unclear how far tiltrotors would penetrate into the markets seined by the generally more cost-effective jet shuttles. Without similar time savings over less expensive commuter feeder flights from small communities, tiltrotor service

88 Norwine, op. cit., footnote 10.

89 Federal Aviation Administration, op. cit., footnote 86, p. 6.

90 John Zuk, chief, Civil Technology Office, NASA Ames Research Center, personal communication, Apr. 11, 1991.

91 Chris Basham, vice president, Charles Willis & Associates, Inc., personal communication, May 20,1991.

92 Ibid.

would be economically feasible only if subsidized. Replacing atypical turboprop roundtrip feeder flight with 39-seat tiltrotor service would cost about $500 extra[93] but would free one "slot" that could be used by a larger and more productive aircraft.[94] This amounts to only a few dollars each for passengers on a 300-seat jetliner, but is more than the typical landing fee charged to the same aircraft. With the exception of flights at the four "slot-controlled" airports, airlines have little incentive to free runway slots, since this would be equally helpful to competitors. Furthermore, Federal regulations[95] prohibit the transfer of commuter slots to large jetliner flights.

Individual airlines have little interest in pushing for commercial tiltrotor development. While tiltrotor passengers and the aviation system as a whole might benefit from tiltrotor service, airlines see mostly risks and no additional profits over the status quo. Thus, the market for commercial tiltrotors is speculative, even if a suitable infrastructure were available and airlines and local communities accepted tiltrotor operations, both of which are far from guaranteed.

The time savings of tiltrotor service hinges on well-situated vertiports. Since tiltrotors do not need runways, 5-acre or smaller vertiports might be built at accessible locations where conventional airports would be environmentally unfeasible or prohibitively expensive. But aircraft noise is a serious problem for airport operators and airlines, and is the leading obstacle to community acceptance for tiltrotor. On the other hand, tiltrotor engineers predict that less noise will reach the ground from tiltrotors than from conventional airplanes or helicopters.

The capabilities of airside infrastructure are also essential to tiltrotor success. Real estate height restrictions and noise will be kept to a minimum if tiltrotors fly steep angles into and out of urban vertiports, but this requires advanced guidance technology and procedures. If tiltrotors make inroads into the busiest intercity travel corridors, they will increase substantially the number of daily flights in the ATC system. Three to five tiltrotors would be needed to carry the passengers served by each jetliner. Although tiltrotors might fly in new or less crowded corridors, compatible ATC capabilities must be ensured lest tiltrotors overcome one form of congestion just to create another.

To enhance public acceptance of tiltrotor operations, technologies need to be perfected that improve rotor designs to reduce noise; ensure operating safety through well-tested cockpit instruments, controls, displays, and pilot training procedures; and enable steep flight paths to and from vertiports. Each of these research, development, and demonstration efforts is equally valuable to most civil VTOL aircraft.

Given these uncertainties, private industry and investors have not committed the substantial funds needed to develop a commercial tiltrotor. The Federal Government has spent over $2.5 billion for XV-15 and V-22 development programs,[96] and private industry has invested another $200 million to $300 million on military tiltrotor technology.[97] U.S. industry would have to inject around $1 billion to $1.5 billion more to produce a commercial tiltrotor.[98]

Without Federal management and financial support for infrastructure and precommercial tiltrotor technology development and testing, U.S. industry will not produce commercial tiltrotors in this decade. If the V-22 program is continued, enough engineering and operational experience might be gained for industry and investors to make firm decisions, either pro or con, regarding commercial tiltrotor production. Industry observers believe that the V-22 design is unacceptable for most commercial transport applications, due to economic and civil performance penalties inherent in meeting military requirements. However, some V-22 structural and propulsion designs and components might be directly transferable to a commercial tiltrotor. Because it has worked closely with DOD to

93 The average Northeast Corridor commuter route (in the Phase II market base) is 172 miles one way and seined by 30-seat turboprop aircraft.

94 The extra tiltrotor "cost per-slot vacated" could be reduced significantly if fewer tiltrotor flights (but equivalent weekly passenger capacity) were used. However, passengers generally consider lower frequencies as a decline in service quality.

95 14 CFR 93, Subpart K.

96 Boeing Commercial Airplane Group et al., Phase 11 Summary, op. cit., footnote 8, p. 4.

97 Federal Aviation Administration, op. cit., footnote 86, p. 12.

98 Norwine, op. cit., footnote 87.

collect data from the V-22 flight test program, FAA is well positioned to certify a V-22 for noncommercial, civil operations by 1995 if a sponsor requests it.

The national benefits and industrial competitiveness implications stemming from commercial tiltrotor need further study, especially if significant Federal support for a U.S.-produced vehicle or the accelerated development of tiltrotor infrastructure is considered. Currently, the United States has about a 5-year development lead worldwide in tiltrotor technology, and with over one-half the potential demand for commercial tiltrotors overseas, this suggests a possibly favorable trade position. However, there is foreign interest in developing high-speed VTOL aircraft and producing commercial vehicles. Regardless of Federal and industry decisions for tiltrotor, the Ishida Group of Japan will likely sell the first high-speed VTOLaircraft in the civil market. However, the Ishida tiltwingwill be designed, developed, and produced in the United States.

If tiltrotor service can overcome air and ground congestion, and even reduce delays at busy airports, it could enhance domestic productivity. But these gains must be balanced with the changed noise patterns, higher energy consumption, and increased air traffic that would arise from tiltrotor operations.