A Research Study: Missions and Applications: Civil Tiltrotor
Sponsored By
Federal Aviation Administration
National Aeronautics and Space Administration
Department of Defense

Government Executive Steering Group

FAA
Craig Beard (Chair)
Larry Andriesen

NASA
John Burks
Ray Whitten

DOD
William Schaefer
Lou Herrick.
LTC, U.S. Army

Study Management

NASA ARC
John Zuk, Study Director
Cliff McKeithan, Study Manager
Tom Galloway, Technical Monitor

Study Conducted By

Boeing Commercial Airplane Company
P.O. Box 3707, Seattle, WA 98124

Team with
Bell- Textron
Boeing Vertol
July 1987

Civil Tiltrotor Applications Study

In 1983, an FAA-sponsored National Rotorcraft Program sought to identify improvements to the national interurban transportation networks and determined that conventional helicopters did not have the potential to satisfy requirements because of a lack of capacity, high operational costs, and high noise levels. Tiltrotors, it was felt, offered better potential to improve interurban air transport service.

In 1985, FAA Administrator D. D. Engen proposed a joint civil tiltrotor study with NASA and DOD that would capitalize on development of the military V-22 tiltrotor and document the potential of the commercial tiltrotor transport market.

This document summarizes the results of a study sponsored by FAA, NASA, and DOD on the mission and applications of a civil tiltrotor.
Summary

Highlights:

National Issues
- V-22 technology addresses several national issues.
  - U.S. prominence in aviation
  - Airport congestion relief
  - Technical and industrial competitiveness
  - Balance of trade

Market Summary
- Civil tiltrotor is a unique vehicle with a large market potential, particularly in high-density market. Pressurized versions show especially high potential.
- Tiltrotor is superior to multi-engine helicopters under most conditions.
  - Twice the speed and longer range
  - Lower operating costs
  - Better community acceptance
  - Better passenger comfort
- Tiltrotor is competitive with fixed-wing aircraft under certain conditions.
  - VTOL capability and time savings are key to success
  - Greater convenience could result in capture up to 2/3 of high density markets
- Market penetration depends on configuration, economics and size. Assessment is difficult because of new transportation system.
  - All new design: 300-1400 units
  - V-22 derivatives: 50-700 units
- Primary market is in North America (65%-75%).

Technical Summary
- Six configurations analyzed (8-75 passenger).
  - Includes V-22 derivatives and new designs
  - All designs based on V-22 technology
- V-22 derivatives with pressurized fuselages can accommodate 50 passengers and meet design range objective [600 nmi].
- Passenger and community acceptance is anticipated [Low noise, vibration and emissions].
- Tiltrotors can operate in current airspace; however, improvements are needed to exploit tiltrotor capabilities for competitive service.
- Early development of certification criteria is a high priority.

Potential Risk Areas Identified
- Technical validation.
  - Pressurized composite fuselage
  - Competitive cost designs
  - Aerodynamic improvement
  - High performance configurations
- Certification validation.
  - Engine out criteria
  - Failure mode criteria
  - Flight deck operations
  - All weather operation
- Infrastructure.
  - Vertiport design, location, availability
  - Adaption into National Airspace System
- Operational characteristics.
  - Route proving
  - Terminal access
- Marketing.
  - Public perception and acceptance (safety, noise, ride comfort)
  - Economic competitiveness
  - Development of supporting infrastructure
  - Business payoff 10 years plus
Carena

• Continue development of atmosphere
• Certification criteria for powered lift
• Integration into the National Aerospace System
• Advanced of precision navigation equipment
• New terminal instrument procedures to take
• Areas
• Ventilators currently located in metropolitan

Infrastructure Planning and Development

- Following integration
- Pressurized composite fuselage
- Laminar configuration
- High performance and technologies
- Optimization of systems and configurations
- Materials and production methods
- Reduce risk and cost through design concepts

Civil Flight Technology Development

System, including:

- Develop a National Plan for a Flight Test Plan
- Technology Demonstration Plan

Short-term actions:

- Key civil flight development to V2Z program
- Work on infrastructure and flight demonstration
- Development of civil flight development
- Continue FAA/NASA/DOD/Industry cooperation
- Continue development of atmosphere

- Develop financial options and schedule
- Define relationships to infrastructure needs
- Support certification criteria
- Identify vehicle candidates
- Identify key technologies

Flight Technology Demonstration Plan
Background: XV-15 and V-22

Tiltrotor aircraft combine features of helicopters and fixed-wing aircraft. They have the vertical takeoff and landing ability of the helicopter and the cruise speed, range, and fuel economy of fixed-wing aircraft.

Tiltrotors achieve this by the use of rotors that operate like helicopter rotors during takeoff and landing, then tilt to horizontal thrust to act like turboprop propellers during cruise.

The military V-22 Osprey tiltrotor, on which this study was based, is the result of more than 30 years of tiltrotor development, starting with the Bell XV-3. In 1977, two XV-15's were built as proof of concept prototypes.

Funded by NASA and the Army, the XV-15's have accumulated more than 800 hours of testing, and they continue to serve as testbeds to refine tiltrotor concepts, prove new components and systems, and demonstrate the controllability, performance, and community compatibility of tiltrotors.

The V-22 Osprey is now in full-scale development, with its first flight scheduled for mid-1988. The V-22 is a multimission military aircraft and a large quantity are programmed for the Marines, Army, and Air Force.

The V-22 Osprey has these features:
- articulating wingtip rotors and nacelles
- composite airframe
- advanced cockpit and avionics
- fly-by-wire control systems
- folding rotors and wings
- fixed-wing maintenance concepts

Potential commercial tiltrotor service offers these advantages:
Over helicopters:
- Higher cruise speed
- Lower noise
- Lower vibration
- Superior economics

Over fixed-wing transports:
- Convenient downtown service
- Operational flexibility
- Competitive economics
XV-15 Tiltrotor Research Aircraft

Cruise

Transition

Takeoff
Introduction

This study resulted from a memorandum of agreement among FAA, NASA, and DOD. The general objective of the MOA was:

"... 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..."

This study addressed certain aspects of the general objective. Boeing Commercial Airplane Company (BCAC) was awarded a contract, teamed with Bell Helicopter and Boeing Vertol.

Eight study tasks were defined:

1. Candidate Market Requirements: potential markets and their operational and design requirements.
3. Facility Requirements: ground facilities needed for viable civil tiltrotor operation.
4. Operational Analysis: operations of different configurations in each candidate market. Also, impact of higher cruise speeds.
5. Economic Evaluation: investment costs, cash operating costs, operator profitability.
6. Technology Spinoffs: V-22 technologies and how they can be used in other applications.
8. Documentation: written and oral reports.

Study Philosophy

The study's philosophical design is shown below. The method involved determining those features of tiltrotors that were desired by the market, designing a vehicle to fit those requirements, then assessing the difficulty, risk, and expense of achieving those features.

This iterative process produced high-confidence data: the questions of "what does the market want?" and "what is its value?" are answered relative to the competition.

Marketing-Oriented Tasks:

1. Candidate Markets
   - Missions
   - Design Objectives

2. Aircraft Functional Characteristics
   - Configurations

3. Facilities Requirements

4. Operational Analysis

5. Economic Evaluation

6. Technology Spinoffs

7. Market Assessment

8. Recommendations and Documentation

Civil Tiltrotor Study Process
more detailed analysis examined in detail and are proposed for further
The study was broad in scope because of the
need to examine coordination to the study team through coordination
and its role in overall change and provided guidance and
Boeing Vertol and Bell Helicopter provided technical
Boeing Commercial Airplane Company (BCAC) was
designated as contact lead and provided study
indicated

The organization of the advisory study team is as
was expected to ensure effective com-
were to monitor progress and ensure effective com-
lar and government interests in this study, a government-standin
because of the broad interests by industry and gov-

Organization

Management Committee
R. Mayer (Conv)
C. Longridge (R. Adelstein)
J. Malen

Executive Council
J. Calway - Tech. Monitor
cmckelvey - study manager
J. Zirk - Study Director
NASA ARC

Government Executive Steering Group
Lt. Col. Hertick

DOD

FAA

NASA

DOD

NASA
Methodology:
Candidate Markets

The objective was to identify the most promising areas of potential commercial application of the civil tiltrotor and thereby provide a focus for marketing and engineering analysis. To do so, three different perspectives were explored:

- a survey of prospective users, to identify their needs.
- an extensive review of previous studies, to place the civil tiltrotor in historical perspective.
- examination of existing inventories of fixed-wing and helicopter aircraft, from standpoint of size, range, and geographic distribution, to identify appropriate market segments.

<table>
<thead>
<tr>
<th>User Groups</th>
<th>Vehicle Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corporate/Executive</td>
<td>High Density Passenger</td>
</tr>
<tr>
<td>Comm. Operators</td>
<td>Cargo/Package Express</td>
</tr>
<tr>
<td>Civil Government</td>
<td>Developing Region</td>
</tr>
<tr>
<td>Offshore Oil</td>
<td>Resource Development</td>
</tr>
<tr>
<td>Other</td>
<td>Corporate/Executive</td>
</tr>
<tr>
<td></td>
<td>Public Services</td>
</tr>
</tbody>
</table>

Surveys
- Bell/Vertol/Aerospatiale/This Study
- 312 Potential Users

Market Surveys

Existing Inventory (Size Distribution)

Existing Inventory (Geographical Distribution)

Includes:
- All Nonmilitary Helicopters
- All Nonmilitary Passenger Multiengine, Fixed-Wing Turbine Aircraft (Less Than 100 Seats)

North America

Total Units Worldwide = 35,650
Vehicle Design Guidelines

- V-22 derivative or technology base:
  - twin engines
  - composite airframe
  - tilting wingtip mounted rotors
  - fly-by-wire
  - advanced cockpit displays
- 600 nmi design range, vertical takeoff with one engine inoperative (OEI Hover)
- 800 nmi design range with rolling takeoff from 750 ft field (STOL)
- Commuter mission profile with FAR reserve fuel requirements
- All federal aviation regulations met for safety, including Category A operations
- Ramp self-sufficiency: airstairs, APU, powerback
- Helicopter NPRM for 30 sec emergency power rating assumed
- Pressurized fuselage
- Normal passenger accommodations and amenities:
  - seating at 30 in. pitch
  - lavatories and galley (hot meal with beverage)
  - full cabin heating and air conditioning
  - pressurization desired
Study Results

The civil tiltrotor is a unique vehicle with a large market potential. V-22 derivatives offer some market penetration, but new designs are required to meet full potential market. Pressurized versions, in particular, show a high potential in several markets.

The civil tiltrotor is superior to multi-engine helicopters in most conditions, in performance as well as cost. Specific design studies for lower construction and operating costs are required to assure maximum viability in the civil marketplace.

For the civil tiltrotor to achieve full potential benefits of congestion relief, a system infrastructure geared to its unique capabilities is needed.

Six tiltrotor configurations were analyzed, including three V-22 derivatives. Several important conclusions were reached about the configurations. V-22 derivatives with new pressurized fuselages and modest engine growth can meet the 600 nmi design range and carry over 50 passengers. Additional capacity (still meeting the 600 nmi design range) is possible with all-new configurations.

The civil tiltrotor can operate under current rules governing use of the airspace; however, changes that exploit the unique characteristics and capabilities of the tiltrotor will improve its competitiveness.

The importance to the commercial market of one engine inoperative (OEI) hover takeoff capability cannot be overstated. However, if a very short runway (750 ft or shorter) is used, the OEI hover range can be more than doubled, as shown by the CTR-1900 payload-range curve to the right.

### Potential Market Demand (Year 2000)

<table>
<thead>
<tr>
<th>Seating</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-15</td>
<td>570</td>
</tr>
<tr>
<td>16-25</td>
<td>625</td>
</tr>
<tr>
<td>26-35</td>
<td>310</td>
</tr>
<tr>
<td>36-45</td>
<td>1430</td>
</tr>
<tr>
<td>46-55</td>
<td>870</td>
</tr>
<tr>
<td>56-100</td>
<td>400</td>
</tr>
</tbody>
</table>

### Mission Demand (Year 2000)

<table>
<thead>
<tr>
<th>Mission</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Density</td>
<td>400 to 1200</td>
</tr>
<tr>
<td>Corporate/Executive</td>
<td>175 to 475</td>
</tr>
<tr>
<td>Resource Development</td>
<td>85 to 325</td>
</tr>
<tr>
<td>Cargo/Package Express</td>
<td>80 to 120</td>
</tr>
<tr>
<td>Low Density/Developing Region</td>
<td>20 to 85</td>
</tr>
<tr>
<td>Public Service</td>
<td>35 to 75</td>
</tr>
</tbody>
</table>

### Payload Range (CTR 1900)

- **Vertical Takeoff Mode**
- **Short Takeoff Mode**

### Potential Market Application (Year 2000)

- **Passengers**
  - 19
  - 16
  - 12
  - 8
  - 4
  - 0

- **Range (nmi)**
  - 0 to 200
  - 200 to 400
  - 400 to 800
  - 800 to 1200
  - 1200 to 1400

- **Payload Range (CTR 1900)**

Note: Categories are mutually exclusive and cannot be added.
Public Sector: A wide range of missions were selected for some applications. One change version of the Y-22 (CT-22B) is also being considered.

Adaptable:

calling (passenger) would add to the market, a "quick-maneuver" capability to reach a target. A "quick-change" capability is likely to be supported by various scenarios of operations in metropolitan business centers. e.g.

Commuter/Express: Flights are low noise and:

Dense/Developing Region: A broad

to the market.

Convenient: Business travelers.

Comfort: Executive.

City/Regional:

High Density Market: Flights could capture 1/3

Study Results (continued)
Recommendations:

The civil tiltrotor's operational features are attractive to commercial markets, and a very large market potential awaits development of the tiltrotor.

To develop a viable market, however, not only the aircraft—but an entire and cohesive tiltrotor transportation system—is required. A national plan for action needs to be developed, one which considers all aspects of a transportation system.

To the passenger on a portal-to-portal trip, the system needs to be perceived as accessible, safe, affordable, and convenient. Costs must be economically justifiable in terms of the value of time saved and the ease of making the entire trip.

In terms of competition, the tiltrotor does not have the luxury of beginning at "square one." It will come into service in a sophisticated, highly efficient, and deregulated environment, the modern air transportation system. It must compete on its merits in this setting.

Tiltrotor aircraft promise both a solution and a challenge. The U.S. leads this technology, but efforts outside the U.S. are also underway. Early U.S. development of a civil tiltrotor could create the benefits of a new industry and a new transportation system, but it carries risks: technical, operational, regulatory, and financial.

With the foregoing in mind, the following elements of a national plan for action on the civil tiltrotor are recommended:

- Continue studies to optimize tiltrotor configurations through use of advanced technology and low-cost designs.
- Develop an integrated civil tiltrotor transportation system plan, including appropriate infrastructure, operating environment regulations, and a technology demonstration plan.
- Continue the cooperation existing between government, industry, and customers in follow-on civil tiltrotor development program.
Design Improvements

Recommedations:
Recommendations: Testing, Simulation, Demonstration

Flight testing and ground-based simulation work are also recommended. These are needed to better understand pilot workload and aircraft response to an OEL condition during takeoff, landing, and transition, and to better formulate proper power margins.

For commercial service, route proving (with participation by FAA, airlines, and communities) will provide a better understanding of the operational features of the tiltrotor and allow simulation of air traffic control.

To accomplish these activities, a program plan needs to be developed to validate acceptable technical and operational criteria for civil tiltrotor transport service. Much technical validation can be accomplished by computer simulation, wind tunnel testing, and detail analysis, but the tiltrotor offers such a new concept that it will require flight validation to show proper integration of the technologies of powered lift, vertical takeoff, and transition to fixed-wing operation. Data must also be accumulated to show reliability of service equal to that of the present civil air transport system. The plan will determine the government/industry business arrangements, including cost, timing, and participation. It will also identify potential demonstrator aircraft, such as the XV-15, V-22, V-22 derivative, or a new pressurized tiltrotor.

The plan should include an operations plan so that the tiltrotor’s attributes and needs can be identified to potential operators, regulatory agencies, and the public. This will ensure an effective transportation system and reduce market risk.

There are many areas to be evaluated: frequency of service, locations for vertiports, facility needs, economics of operation, IFR procedures, minimum aircraft operating separation, public acceptance, and a host of other factors. All of these can be examined through a well-designed demonstration program.

The cost of a demonstration program, while significant, is low compared to the public benefits anticipated and the value of reduced technological risk. It would be an inexpensive contribution toward long-term solutions of several national issues:

- U.S. pre-eminence in aviation
- Airport congestion
- Technical and industrial competitiveness
- Balance of trade competitiveness

Recommendations: Timing

Development of a civil tiltrotor transportation system needs to be keyed to the military V-22 tiltrotor program for maximum efficiency of development funds and to reduce risks. The civil tiltrotor development plan should augment and complement the V-22 program and must keep itself ahead of expected foreign competition.
**Overview**

**Configurations**

To optimize the acquisition system design, 156 engines (4x 31 engines) are needed. The largest possible number of the engines are used on the CTR-750. It is the largest configuration of an engine.

The CTR-750 is the largest configuration of the engine.

- Engine weight:
  - 156 engines (4x 31 engines) are needed.

- Range and speed:
  - CTR-1900 with the V-720.

- Configuration change:
  - The CTR-750 is the result of a new design and upgraded RIM-222 range and speed. The CTR-750 is approximately the same physical size as the CTR-22B. A 600 nm range is achieved with 52 passengers in an executive interior. The CTR-22B uses the V-720 wing and propellers. Several configurations (V-711, V-712, V-713) are available. The CTR-750 is the largest configuration of the engine.

### Characteristics

<table>
<thead>
<tr>
<th>CTR-800</th>
<th>CTR-22B</th>
<th>CTR-22C</th>
<th>CTR-22D</th>
<th>CTR-750</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>4x 31 engines</td>
<td>4x 31 engines</td>
<td>4x 31 engines</td>
<td>4x 31 engines</td>
</tr>
<tr>
<td>Range (nm) (OEI hover)</td>
<td>79.980</td>
<td>77.50</td>
<td>77.50</td>
<td>77.50</td>
</tr>
<tr>
<td>Cruise Speed (kts)</td>
<td>227</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>TopW (OEI hover) (kts)</td>
<td>215.75</td>
<td>215.75</td>
<td>215.75</td>
<td>215.75</td>
</tr>
<tr>
<td>Wing/Rotor Span (ft/hr)</td>
<td>32.2</td>
<td>32.2</td>
<td>32.2</td>
<td>32.2</td>
</tr>
<tr>
<td>Overall Length (ft)</td>
<td>41.5</td>
<td>41.5</td>
<td>41.5</td>
<td>41.5</td>
</tr>
<tr>
<td>No. Passengers</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

### Derivative Designs

**CTR-750/A/B**: A summary of the study follows:

- Engineering design:
  - 156 engines (4x 31 engines) are needed.

- Range and speed:
  - CTR-1900 with the V-720.

- Configuration change:
  - The CTR-750 is the result of a new design and upgraded RIM-222 range and speed. The CTR-750 is approximately the same physical size as the CTR-22B. A 600 nm range is achieved with 52 passengers in an executive interior. The CTR-22B uses the V-720 wing and propellers. Several configurations (V-711, V-712, V-713) are available. The CTR-750 is the largest configuration of the engine.

### Table

<table>
<thead>
<tr>
<th>Model</th>
<th>16'100</th>
<th>17'83</th>
<th>9'140</th>
<th>6'850</th>
<th>8'905</th>
<th>9'580</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM 1</td>
<td>2625</td>
<td>2100</td>
<td>3400</td>
<td>4300</td>
<td>5400</td>
<td>6500</td>
</tr>
<tr>
<td>RPM 2</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
</tr>
<tr>
<td>RPM 3</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
</tr>
<tr>
<td>RPM 4</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
<td>222</td>
</tr>
</tbody>
</table>

### Diagram

- CTR-800
- CTR-22B
- CTR-22C
- CTR-22D
- CTR-750
Configurations:

Derivative Designs

V-22 military tiltrotor derivatives are those in the CTR-22A series (A, B, C, D). The CTR-22A/B are minimum change configurations and retain the V-22 drive train and primary structure. All military equipment, including cargo ramp, is retained, a passenger galley, and windows and doors are added.

The CTR-22B is the CTR-22A with updated transmission and an unpressurized fuselage. The design range results in 600 nmi. Like the CTR-22A, the CTR-22B carries 31 passengers in three-abreast seating, lavatory, and luggage is carried inside the fuselage.

The CTR-22C has the V-22 drive train and a new, larger, pressurized fuselage that carries 39 passengers for the 600 nmi range. This is fully responsive to market requirements. 39 passengers are seated in three-abreast seating, and baggage is carried in the fuselage rather than in the outboard spotters of the CTR-22A/B.

The CTR-22D expands the CTR-22C to a larger four-abreast fuselage that seats 52 passengers. With 39 passengers aboard like the CTR-22C, the 600 nmi design range is achieved. With a full load of 52 passengers, the range drops to 280 nmi. Because of the wider fuselage, the V-22 center wing section is wider in this model. Moving the rotors outward, while adding additional lift, creates substantial benefits in reduced cabin noise levels, and better passenger seating. The CTR-22D should be optimized for passenger capacity and range.
Configurations: "All-New" Designs

Three "all-new" civil tiltrotor designs were developed:

- The CTR-800, an 8-passenger executive tiltrotor with XV-15-type configuration and similar physical size.
- The CTR-1900, a 19-passenger model with a low wing, canard, and "V" tail.
- The CTR-7500, a 75-passenger model with low wing and conventional tail.

All designs make use of V-22 military tiltrotor technology, including composite structure, systems concepts, and flight deck configuration. In addition, they incorporate design elements related to civil needs, such as pressurized fuselage, airstair, and number of exits.

The CTR-800 is a design for corporate/executive use, with appropriate accommodations for seating 8 passengers. In cross-section, the CTR-800 is larger than the Lear Jet.

The CTR-1900 design resulted from a trade study that compared various combinations of main wing locations (high, low), tail configurations ("V," "H," conventional), and use of canards. The CTR-1900 incorporates a low wing, "V" tail, and canards. Further study is needed to optimize relationships between these elements, but initial results of the trade study indicate this design has the lowest drag and weight of those studied.

The CTR-7500 carries 75 passengers in a five-abreast configuration. An alternate design would carry the same number of passengers in a six-abreast arrangement. Again, additional study is needed to determine the optimum fuselage and the tradeoffs involved in the two-engine design versus designs using three or even four engines.
Configurations: V-22 vs. "All-New" Designs

There is no simple answer to the question: which are better, the V-22 derivatives or the all-new designs? Both have their benefits—and their markets.

The V-22 derivatives use an existing design, appropriately modified for civil use. They use the V-22 propulsion system, rotors, transmissions, controls, and flight decks, and technological advances inherent in the V-22: composites, fly-by-wire, advanced displays and control systems, and others.

The "all-new" designs also make use of V-22 technological advances; in that sense, they are not "all-new." But the CTR-1900 and CTR-7500 do differ substantially from the CTR-22 series and offer a number of advantages:

- Layout not restricted by dictates of aircraft carrier dimensions or the need for a rear cargo door.
- No need for battle survivability (bladder fuel tanks, ballistic tolerance, etc.).
- Fuselage design centered around passenger needs (ride comfort, pressurization, inside baggage storage, better cross-section, etc.).
- More emphasis on design/build in commercial environment, resulting in potential cost savings.

Typically, emerging military tiltrotor technology will emphasize advances in maneuverability and survivability; civil tiltrotor technology will emphasize features leading to greater economies and comfort. The challenge is to effect the maximum transfer of technologies between the two, with the goal being to maintain the momentum gained in both programs—the V-22 and the civil tiltrotor.
Markets: Overview

Four major conclusions were reached about all the candidate markets studied:

- Civil market requires tiltrotors that meet its needs (VTOL, OEI hover, pressurization, normal amenities, low noise, high reliability, all-weather capability, competitive operating costs, safety).
- Civil tiltrotors, if produced with market-responsive features, will have a very large market potential. Several sizes are needed for various applications.
- An emerging technology with new concepts, the tiltrotor must compete in a mature, sophisticated, efficient, and deregulated environment. It must do so on its merits.
- Because of the tiltrotor's unique operational features, it is anticipated that significant markets will develop in unforeseen areas.

Specific conclusions for the individual candidate markets are discussed on the following pages and are summarized here:

- High-density: Tiltrotors with greater than 35-passenger capacity are desired. Supporting infrastructure must be developed for the high-density market to be exploited.
- Package express: Advantages include later pickup times and reduced ground times. Good application for intra-metropolitan service, feeders to trunk lines.
- Resource development (offshore oil): Current platforms limit tiltrotor size; newer platforms accept larger tiltrotors. Better economics (versus helicopters) favor tiltrotor in this market.
- Public service: Good potential in all public service areas.
- Corporate/executive: Tiltrotors can replace both helicopters and airplanes in this market, a decided advantage for customers.

### Market-Based Configurations

<table>
<thead>
<tr>
<th></th>
<th>Corp/Exec</th>
<th>Government Public Service</th>
<th>Low Density</th>
<th>Resource Development</th>
<th>Cargo/Package Express</th>
<th>High Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Potential</td>
<td></td>
<td></td>
<td>35</td>
<td>85</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>Nominal Market Penetration</td>
<td>● CTR-22B:</td>
<td></td>
<td></td>
<td></td>
<td>50 to 100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● CTR-22C:</td>
<td>100 to 700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>● CTR-22D:</td>
<td>200 to 500</td>
</tr>
</tbody>
</table>

Demand: V-22 Derivatives


**Market Design Criteria**

- FAA Certification
- Power Back
- Ramp Set Sufficiency - Air Start; APU
- Rotor Blades Designed with Manual Folding
- Wing Slow not Required (V-22 Featene)
- All Weather Operation
- Utility: Used for 88% of the U.S. Market
- Noise - Equal to Less Than Current Aircraft
- Cabin Pressurization
- 800 N Range with 750 lb STOL
- 600 N Range with 575 lb Takeoff

**Demand: All New Designs**

<table>
<thead>
<tr>
<th>Units</th>
<th>Potential Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>High</td>
</tr>
<tr>
<td>Express Package</td>
<td>Cargo</td>
</tr>
<tr>
<td>Resource</td>
<td>Development</td>
</tr>
<tr>
<td>Service</td>
<td>Public</td>
</tr>
<tr>
<td>Gov't</td>
<td>Commercial</td>
</tr>
<tr>
<td>Size (Seats)</td>
<td>Category</td>
</tr>
</tbody>
</table>

**Potential Tiltrotor Replacement or Eligible Existing Equipment**

<table>
<thead>
<tr>
<th>Category</th>
<th>Size</th>
<th>Potential Replacement of Units</th>
<th>Total Percent of Units</th>
<th>Total Percent of Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-25</td>
<td>42</td>
<td>28</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>26-50</td>
<td>32</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>51-70</td>
<td>18</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>7+</td>
<td>18</td>
<td>9.15</td>
<td>9.15</td>
<td>9.15</td>
</tr>
</tbody>
</table>

**Legend**

- 55% of the market in North America (65-75%)
- Existing inventory of fixed-wing and helicopter
- Existing inventory is very large. Dirigible could
- Potential target is very large. Dirigible could

**Study Size**
Markets:
High-Density Market

The New York—Boston market was selected as representative of high-density passenger commuting: the worst airport delays in the U.S. exist in this area (see chart to right). As just reported by the FAA, airlines logged an average of 2000 hr of delays per day in 1986, up 25 percent from 1985. FAA predicts that the number of seriously congested airports will increase from 16 in 1986 to 58 by the year 2000.

Civil tiltrotors could capture one-third to two-thirds of this market. Key to tiltrotor’s success is its VTOL ability, perceived as a necessity at one or both ends of each trip.

The VTOL capability would allow passengers to begin and end their business trips near home, and to arrive at their metropolitan business destinations.

Market penetration of the civil tiltrotor is dependent on the form of service made available to the commuter. Point-to-point service would account for a 64% market share; through-plane service would draw 61% of the market; and connect-hub service would draw 36% (see chart at bottom right). However, through-plane and hubbing service concepts permit the use of fewer but larger aircraft. The resulting economics of scale may be a factor in achieving tiltrotor portal-to-portal cost parity with today’s short-haul transport system.

Another factor will be the number and location of vertiports. In the New York, Boston, and surrounding area, for example, 18 vertiports properly located would yield good penetration. Initially, it is expected that existing airfields could support some tiltrotor service; single-purpose vertiports would be added as service is more completely established.

Other high-density markets examined were Japan and western Europe. In both areas, civil tiltrotor would have good success, based on preliminary analysis, but additional detailed study to the level of detail of the New York—Boston corridor needs to be performed.

### Delays at Major U.S. Airports

![Delays at Major U.S. Airports](chart)

#### New York Boston Example

<table>
<thead>
<tr>
<th>Type of Service</th>
<th>Avg Trip Time Advantage</th>
<th>Market Share</th>
<th>Optimum Tiltrotor Size (Seats)</th>
<th>Tiltrotors Required*</th>
<th>Cash Cost (Per Pass.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point-to-Point</td>
<td>2 + Hr</td>
<td>64%</td>
<td>36</td>
<td>60</td>
<td>Base</td>
</tr>
<tr>
<td>Through-Plane</td>
<td>1:55</td>
<td>61%</td>
<td>62</td>
<td>45</td>
<td>-10%</td>
</tr>
<tr>
<td>Connect Hub</td>
<td>1:20</td>
<td>36%</td>
<td>76</td>
<td>20</td>
<td>-14%</td>
</tr>
</tbody>
</table>

*Year 2000
will remain limited
are transport-the potential for dilution in this market
mined increases—and with it the demand for new
dilution’s full effect industry for resource explo-
monic development is essential to the success of
in all of the low-density markets examined, etc.
Heads of foreign firms can be
this particular advantage in serving new demand-
model of registering of those physicians, the dilution
now in service and reduce the need for oil-re-
could replace many of the fixed wing STOL aircraft
richevision of year-round transportation. The dilution
and all relevant is well-established as the only feasible
very small. Similar statements are widely spaced
les conditions are extreme and the population is
AirAsia wants special mention as it represents a
merit support would be needed.
source could increase the ability of the bus guar-
we are generally poor for these reasons, dilution
fication criteria is relatively underdeveloped and the econ-
its present in the region. Transportation policies are
any political entities are
The Caribbean region was examined as a low-
the low-density market

Caribbean Passenger Routes

<table>
<thead>
<tr>
<th>Distance (Miles)</th>
<th>Passengers/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>25,931</td>
</tr>
<tr>
<td>440</td>
<td>29,546</td>
</tr>
<tr>
<td>360</td>
<td>30,911</td>
</tr>
<tr>
<td>200</td>
<td>31,267</td>
</tr>
<tr>
<td>120</td>
<td>31,988</td>
</tr>
<tr>
<td>120</td>
<td>34,685</td>
</tr>
<tr>
<td>120</td>
<td>36,559</td>
</tr>
<tr>
<td>200</td>
<td>42,123</td>
</tr>
<tr>
<td>240</td>
<td>44,676</td>
</tr>
<tr>
<td>234</td>
<td>49,536</td>
</tr>
<tr>
<td>240</td>
<td>49,536</td>
</tr>
<tr>
<td>208</td>
<td>77,133</td>
</tr>
<tr>
<td>208</td>
<td>77,133</td>
</tr>
<tr>
<td>108</td>
<td>79,475</td>
</tr>
<tr>
<td>108</td>
<td>79,475</td>
</tr>
</tbody>
</table>

Caribbean Aircraft Inventory

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRJ-700</td>
<td>4</td>
</tr>
<tr>
<td>CRJ-900</td>
<td>5</td>
</tr>
<tr>
<td>CRJ-700</td>
<td>11</td>
</tr>
<tr>
<td>CRJ-700</td>
<td>18</td>
</tr>
<tr>
<td>HS-748</td>
<td>22</td>
</tr>
<tr>
<td>HS-748</td>
<td>25</td>
</tr>
</tbody>
</table>

Low-Density Market

Markets:
- 20-109 passengers
Markets:
Resource Development Market

One of the best potential markets for the civil tiltrotor is in support of the resource development market (i.e., resupply of offshore oil and gas platforms). This is currently one of the biggest and most successful markets for larger helicopters, and the civil tiltrotor has substantial economic advantages due to higher cruise speeds and lower operating costs.

Other resource development markets exist: logging, mining support, resource exploration. But the primary market is offshore oil and gas.

The North Sea plateau was chosen as an indicative market. It represents very large petroleum deposits, and the bulk of its platforms are 150 nmi or more offshore, an especially attractive range for the tiltrotor.

The distribution of the world's oil platforms is shown on the map to the far right. The total number of rigs is shown in tabular form and the projected market penetration for the civil tiltrotor is also shown. As can be seen, the market is large: a total of 324 CTR-1900 tiltrotors, 110 CTR-22A/B's, or 86 CTR-22C's would be required to satisfy the market.

These numbers are conservative as they do not reflect unexplored and undeveloped fields; indeed, the greater range and speed of the tiltrotor could well lead to additional exploration and development activities, since current activities are limited, at least in part, by the short range of available helicopters.

The numbers also do not reflect any other resource development markets besides oil and gas. More market analysis work is required to assess the extent of this additional demand.

It should also be noted that even the first generation of civil tiltrotors (i.e., the V-22 derivatives with unpressurized cabins) are clearly superior to current helicopters. Future generations or refinements of the tiltrotor will be even more desirable in this market.

<table>
<thead>
<tr>
<th>Region</th>
<th>Total Number of Rigs</th>
<th>Percent of Base Case</th>
<th>Units Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CTR-1900</td>
</tr>
<tr>
<td>North Sea</td>
<td>106</td>
<td>100%</td>
<td>51</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>210</td>
<td>198%</td>
<td>101</td>
</tr>
<tr>
<td>Middle East</td>
<td>74</td>
<td>70%</td>
<td>36</td>
</tr>
<tr>
<td>South America/Brazil</td>
<td>51</td>
<td>48%</td>
<td>25</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>37</td>
<td>35%</td>
<td>18</td>
</tr>
<tr>
<td>Far East</td>
<td>30</td>
<td>28%</td>
<td>15</td>
</tr>
<tr>
<td>Other South America</td>
<td>28</td>
<td>26%</td>
<td>14</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>25</td>
<td>24%</td>
<td>13</td>
</tr>
<tr>
<td>West Africa</td>
<td>23</td>
<td>22%</td>
<td>12</td>
</tr>
<tr>
<td>Southern Asia</td>
<td>22</td>
<td>21%</td>
<td>11</td>
</tr>
<tr>
<td>Caribbean/Central America</td>
<td>11</td>
<td>10%</td>
<td>6</td>
</tr>
<tr>
<td>Canadian East Coast</td>
<td>9</td>
<td>8%</td>
<td>4</td>
</tr>
<tr>
<td>Western Europe</td>
<td>8</td>
<td>7.5%</td>
<td>4</td>
</tr>
<tr>
<td>Alaska/Canada (Arctic)</td>
<td>6</td>
<td>6%</td>
<td>3</td>
</tr>
<tr>
<td>Oceania</td>
<td>6</td>
<td>6%</td>
<td>3</td>
</tr>
<tr>
<td>United States West Coast</td>
<td>6</td>
<td>6%</td>
<td>3</td>
</tr>
<tr>
<td>Other Africa</td>
<td>5</td>
<td>5%</td>
<td>3</td>
</tr>
<tr>
<td>Alaska West Coast</td>
<td>3</td>
<td>3%</td>
<td>2</td>
</tr>
</tbody>
</table>

Total                     | 324                  | 110                  | 86      |

Note: The size categories are mutually exclusive and cannot be added for total projected requirements

Tiltrotor Potential
Markets: Public Service Market

In the public service market, the customer is the general public, and the costs are borne by the community. Primary missions include police and fire department support, medical transport, drug enforcement, Coast Guard search and rescue, and border patrol.

For the public at large, the tiltrotor offers improved service in terms of flexibility and speed while at the same time reducing the sound levels and possibly the number of aircraft needed to do the same work. Community acceptance should also be greater for this machine because it looks more like the airplanes the public has come to rely on for everyday business activities.

Each mission has a slightly different set of requirements. In general, the civil tiltrotor was found to have very good potential application to this market, as discussed on the balance of this page and the next.

Drug Enforcement

For drug enforcement work, speed, range, and endurance are critical, as is the ability to take off and land vertically from unimproved surfaces. The mission involves interception and pursuit of drug dealers on the ground as well as in the air, in all types of weather, and usually with very little advance warning.

Key to mission success is having the right kind of aircraft available when needed. Because of the tiltrotor's high speed, hover capability, and good dependability, it is nearly ideal for the role—and can supplement both fixed-wing and helicopter aircraft.

The minimum change V-22 (CTR-22A/B) is an ideal candidate: its range is good, it is fast, it is large enough, and its rear ramp (if retained in the design) would facilitate the rapid loading and off-loading of law enforcement personnel. Additionally, the CTR-22A/B has good ballistic tolerance against rifles and more sophisticated weaponry.

Medical Transport

Emergency medical transport is a rapidly growing sector of helicopter use. About 150 EMS programs exist in the U.S., transporting a total of 85,000 patients per year, including 6000 to 7000 in life critical situations.

Tiltrotor potential for displacing helicopters in this market is excellent, especially where distances are greater than can be easily handled by helicopters alone. The tiltrotor's speed and range can reduce transit time and the number of patient transfers required.

With the flexibility to land vertically in relatively small cleared areas, the tiltrotor can pick up the patient close to the initial site of medical intervention. Pressurization and a good ride quality will enhance the ability of the medical attendants to accomplish their tasks and provide a stable environment for the patient. At twice the speed of a helicopter, the patient can be transferred to a major medical facility where proper follow-on care can be administered. With a range in excess of 600 nmi at the lighter mission weights of a medical transport role, the service area of a sponsoring hospital can be dramatically increased, meaning increased revenues for that facility.

For medical transport, a six-to ten-passenger tiltrotor is needed. The CTR-800, an eight-passenger model with a pressurized cabin, meets this need well.

Coast Guard

Coast Guard search and rescue missions provide an excellent market for tiltrotors. Between 1979 and 1983, the USCG launched more than 145,000 aircraft rescue missions, mostly to locations within the 150 nmi range of the new HH-65 helicopter just put into service. Longer missions were handled by the HH-3 helicopter (up to 200-300 nmi) or the HU-35 Falcon jets.

The tiltrotor's range and speed make it ideal for search and rescue. It has a long airborne time, which will improve the ability to patrol areas for survivors, and its ability to fly in all weather conditions (generally bad during rescue missions) and to hover without severe downwash effects would improve rescue efforts.

The CTR-800 would be ideal for short-range recovery; 91% of all short-range recovery missions involve 10 or fewer people.

The CTR-1900 or the CTR-22 series would improve retrieval success on longer range missions because of their 600 nmi range, long search time abilities, and the ability to rescue larger numbers of survivors (longer range missions tend to involve larger numbers of people). At the higher search speeds of a tiltrotor, twice the area can be covered in a hour, compared to a helicopter. Search area expands as a function of time, so the tiltrotor's speed advantage increases the odds of locating victims.

Police

Police applications would be in the area of long-range prisoner transfer, high-priority personnel transport, and for patrol, search and rescue, and ambulance missions. The tiltrotor's versatility is an important attribute for the diversity of police missions.

The CTR-800 is the configuration most likely to be of interest for police applications.

Another potential new mission that relates to the tiltrotors range capability is long-range surveillance of remote terrain.

Fire

Fire departments use VTOL aircraft for command and control, rescue, search, and VIP transport. In most cases, a small tiltrotor would be an ideal substitute for helicopters, especially where range, speed, and endurance are important. For the fire rescue mission, where large numbers of people are involved, a larger tiltrotor (CTR-22 series) could be used.

Smoke jumping is another ideal mission for the aircraft because of its favorable downwash pattern and hovering capability, allowing rappelling or parachuting into the path of a forest fire.
Incumbent Market

<table>
<thead>
<tr>
<th></th>
<th>5'3'0'</th>
<th>5'3'30</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>130</td>
<td>80</td>
<td>210</td>
</tr>
<tr>
<td>Oceania</td>
<td>3'740</td>
<td>840</td>
<td>4'580</td>
</tr>
<tr>
<td>North America</td>
<td>3'240</td>
<td>70</td>
<td>3'310</td>
</tr>
<tr>
<td>Europe</td>
<td>90</td>
<td>350</td>
<td>440</td>
</tr>
<tr>
<td>Central America</td>
<td>800</td>
<td>1'200</td>
<td>2'000</td>
</tr>
<tr>
<td>Asia</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Africa</td>
<td>120</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>**Helicopters</td>
<td></td>
<td></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>**Turboprops</td>
<td></td>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

130 to 200 units: If not available instead of the singe-engine on 130 to 200 units, the larger CR-7000 (192-seat). The larger CR-7000, 800, 100, or 1'200 units, the larger CR-7000, 800, 100, or 1'200 units.

Executive Market

- Corporate/Executive Market: The corporate/Executive market is very high-speed cruise allows them to replace aircraft above at both ends of the traveling journey and their current VTL capabilities offers substantial savings in customer experience. They are less efficient and more expensive, but are designed for the specific needs of the corporate/Executive market. The smaller versions of the civil aircraft offered by other manufacturers are less efficient and require more expensive maintenance.

- South America: The largest market for business aviation. The South America region offers an attractive market for business aviation with a strong demand for executive aircraft due to the high-net-worth individuals and corporate travel. The demand for executive aircraft is driven by the need for quick and efficient travel between major cities and within countries.

- Oceania: The demand for business aviation in Oceania is driven by the need for efficient and cost-effective travel between major cities and countries. The Oceania region offers a growing market for business aviation due to the increasing demand for executive aircraft.

- North America: The North America region offers a strong demand for business aviation, driven by the need for quick and efficient travel between major cities and countries. The demand for executive aircraft is driven by the need for cost-effective travel and the need for corporate travel.

- Europe: The European market offers a strong demand for business aviation, driven by the need for quick and efficient travel between major cities and countries. The European market is expected to grow due to the increasing demand for executive aircraft and the need for corporate travel.

- Central America: The Central America region offers a growing market for business aviation due to the increasing demand for executive aircraft and the need for corporate travel.

- Asia: The Asia market offers a strong demand for business aviation, driven by the need for quick and efficient travel between major cities and countries. The demand for executive aircraft is driven by the need for cost-effective travel and the need for corporate travel.

- Africa: The African market offers a growing market for business aviation due to the increasing demand for executive aircraft and the need for corporate travel.
Markets: Cargo/Package Express

Package express service is growing rapidly, and the tiltrotor offers several advantages in this market: central business district to central business district capability, VTOL capability to allow rapid connection with hubs for longer-distance flights, same day service, and low noise (especially important, since most flights occur at night). The upward trend in package express service will likely continue, driven by the growing trend for businesses to minimize inventories.

Several cargo configurations are shown to the left. The minimum change V-22 (CTR-22A/B), with its unpressurized fuselage and rear cargo ramp, is a candidate for this service. It may well be, in fact, that this market offers the best potential for "proof of concept" for this model.

A complete market study is required to obtain good figures for tiltrotor market penetration. Preliminary analysis shows some acceptance of tiltrotor, however, and an estimate was prepared based on the list of cities below and the number of tiltrotors required to serve each city. This yielded a market potential of 80 units of the CTR-22A/B. With larger machines, and their ability to carry intermodal containers, the potential market could be as high as 120 units.

<table>
<thead>
<tr>
<th>North America</th>
<th>Latin America</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>Buenos Aires</td>
<td>Amsterdam/Belgium</td>
</tr>
<tr>
<td>Boston</td>
<td>Mexico City</td>
<td>Cologne/Frankfurt</td>
</tr>
<tr>
<td>Dallas/Ft. Worth</td>
<td>Montevideo</td>
<td>London</td>
</tr>
<tr>
<td>Denver/Colorado Springs</td>
<td>Rio de Janeiro</td>
<td>Manchester/Northern U.K.</td>
</tr>
<tr>
<td>Chicago/Milwaukee</td>
<td>Sao Paulo</td>
<td>Milan</td>
</tr>
<tr>
<td>Houston</td>
<td></td>
<td>Paris</td>
</tr>
<tr>
<td>New York/Long Island</td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Francisco Bay Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington D.C./Baltimore</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Overview:

Economics:

Cash Operating Cost Comparison

<table>
<thead>
<tr>
<th>Helicopter</th>
<th>Tiltrotor</th>
<th>Turboprop</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.7 hr.</td>
<td>2.0 hr.</td>
<td>4.0 hr.</td>
</tr>
<tr>
<td>1.62 hr.</td>
<td>2.62 hr.</td>
<td>2.97 hr.</td>
</tr>
</tbody>
</table>

Total Trip Time (Portal-to-Portal):
- 4.7 hr.

Aircraft Portion of Trip (Block Time):
- 2.0 hr.

Note:
- Cash cost does not include investment
- 200 nm mission
- 3:1 seat aircraft
Economics: Operating and Maintenance Costs

The graphs opposite show an important reason for the tiltrotor’s favorable operating costs, as compared to the helicopter: lower costs of maintenance. They also show a typical breakdown of maintenance costs, indicating that over half of the maintenance is in the propulsion system.

Equally important, of course, is how the tiltrotor fares against fixed-wing competition. There, fixed-wing aircraft have the advantage; their cash operating costs are lower, to a large extent, because of lower maintenance costs.

It must be noted, however, that operating costs tell only part of the story. Revenues from operations are the offsetting factor, and here the tiltrotor has a potential advantage over fixed-wing aircraft: its greater convenience and time savings can result in greater revenues per passenger.

In all analyses, it was apparent that the differences in maintenance costs accounted for most of the differences in non-investment (cash) operating costs. The fixed-wing turboprops were the cheapest to maintain and the helicopters the most expensive. Tiltrotor costs reflect commercial service, with factors to account for the turboprop mode (cruise) and the helicopter mode (takeoff and landing).
Cost-to-Build Comparisons (Average Cost per Unit over 300 Units)

<table>
<thead>
<tr>
<th>Seals</th>
<th>CTR-7500</th>
<th>CTR-228</th>
<th>CTR-1900</th>
<th>CTR-800</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>+4%</td>
<td>-1%</td>
<td>+26%</td>
<td>-7%</td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Per Unit Costs:

- All-New Designs
- Derivative Designs

Economics:

In any follow-on director work, that is essential to include detailed cost-to-build studies where analysis is needed, however, and it is considered. Standards and factors similarly may excise technology when each is designed in the same commercial to 50% more than a supposed of equal capacity. This study and other general cost studies have per unit basis—is shown in the lowest per chart.

Feasibility studies in completing any analysis of economic manufacturability's profile an element that must be considered that the cost to build shown are excluded of curve in the 1995 time frame. It should also be evident that the Y22 error has been corrected. Original data from the Y22 drawing is based on Y22 estimations and in the case of Y22 is based on 22 estimations. The analysis is indicated by the upper bar graph. This analysis indicates cost-to-build comparisons, including non-recurring costs. The premise is cost to build each of the new principal shown in the left are several important conclusions.
Economics: Market-Based Price

Faredriver methodology was used to develop market-based prices. These were obtained by looking at fixed-wing and helicopter cash operating costs and purchase prices, then backing into an investment price required to make the tiltrotor economically competitive.

For the high-density market, using New York-Boston as an example where tiltrotor would compete with fixed-wing fares, the tiltrotor must receive credit for saved ground access costs ($37 average), plus a credit of $20 for the value of commuter time saved, if it is to be competitive to operators who want a 10% return on investment.

As indicated by the upper bar chart, the resulting revenues will make the worth of the tiltrotor roughly equal to its estimated cost to build (solid arrows). Target arrows are also shown on the upper chart, to indicate 25 percent cost reductions targeted to result from full integration of civil-only requirements during design and build.

The lower bar chart shows the offshore support scenario, where tiltrotors would compete with helicopters. Tiltrotor values far exceed their cost to build in this market, even when fares for helicopters and tiltrotors are equal.

In summary, the civil tiltrotor concept is financially viable, provided:

- Its unique advantages are exploited by a fully developed infrastructure (vertiplots, surface transport interface, air traffic control).
- Tiltrotors large enough to allow economies of scale—in operation and in cost to build—are developed.
- Efforts are continued to provide a vehicle responsive to civil requirements.
- Joint government/industry efforts to develop a civil tiltrotor transportation system are continued.
and ground congestion, benefits in reduced travel time and reduced air
travel will be realized for achieving the maximum lift factor
vertically—beginning in metropolitan urban areas
service is established. It is expected that proceeds
will be provided from existing airport facilities as full-
ly is expected that initial lift service will be part-
Aviation Week: 9/7/89
vertically oriented to cost 94—56 billion for a
design. It is noted that a moderate airport is expedated
situational cost estimates ranged from 511 million for
the cost of land and excluding site costs, vertiport con-
struction costs for urban and suburban, and
ing on the location (urban or suburban), size (5)
vertiport construction costs will vary widely depend-
.space available in at least one direction.
has a large advantage in having unobstructed air
Another possible design shown is the floating verti-
use of property already used for public purposes.
will make it generally free of obstructions and would make
would make advantageous use of available airspace which
possible vertiport above a heavy and support
are shown to the left. The view from afar shows a
Several possible designs were postulated and two
unique location and impact
Each vertiport would be custom designed for its
each day. 4,000 passengers per day each way
area. Each vertiport would serve the area
of New York City including within the N.Y.C. metro
vertiports would be needed within a 300 nm radius
the concept was examined as a special case in that vertiport
35-passenger vertiport as an example vehicle. 18
vertiport facilities needed to support the
vertiport Vertiport:

Facilities
Other Issues:
**Other Issues: Tiltrotor Operational Characteristics**

Tiltrotors have excellent stability and responsiveness, coupled with state-of-the-art flight deck control capabilities. Since they employ both powered lift and aerodynamic forces, they use conventional airplane control surfaces (elevator, rudder, flaperon) and tandem rotorcraft control (differential collective, cyclic tilt, differential cyclic tilt). These are displayed to the right.

Control systems are triple-redundant, making use of full authority digital fly-by-wire control that consists of a primary flight control system, an automatic flight control system, and a mission computer avionics system. Coupled with advanced displays systems, these offer response and stability for optimum handling.

Nacelle rotation accomplishes transition from hover to wingborne lift. The rotor/propulsion system tilts over a range of 97 degrees, and the nacelle angle is synchronized with speed, as shown in the conversion corridor chart. A conversion protection system prevents the aircraft from inadvertent excursions outside the approved airspeed/nacelle corridor shown.

The civil tiltrotor’s flight envelope has been validated by XV-15 performance, as shown at the far right. As can be seen, the tiltrotor has a far broader flight envelope than its fixed-wing or rotorcraft competition.

**Other Issues: Certification**

Tiltrotor certification is the subject of ongoing dialogue with FAA. FAA's draft "Interim Airworthiness Criteria for Powered Lift Transport Aircraft" was circulated for comment during this study; an FAA/industry review was held in 1987. Study groups will be formed to discuss specific certification/opertational issues, which include:

- One engine inoperative (OEI) performance
- IFR alternate fuel requirements

<table>
<thead>
<tr>
<th>Control</th>
<th>VTOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>Longitudinal Cyclic</td>
</tr>
<tr>
<td>(Cyclic Lever)</td>
<td></td>
</tr>
<tr>
<td>Thrust</td>
<td>Collective Pitch Command</td>
</tr>
<tr>
<td>(Power Lever)</td>
<td></td>
</tr>
<tr>
<td>Roll</td>
<td>Differential Collective Pitch</td>
</tr>
<tr>
<td>(Cyclic Lever)</td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td>Lateral Cyclic</td>
</tr>
<tr>
<td>Translation Mode</td>
<td></td>
</tr>
<tr>
<td>(Power Lever)</td>
<td></td>
</tr>
<tr>
<td>Yaw</td>
<td>Differential Longitudinal Cyclic</td>
</tr>
<tr>
<td>(Pedals)</td>
<td>Right Rotor</td>
</tr>
<tr>
<td></td>
<td>Left Rotor</td>
</tr>
</tbody>
</table>
Performance under the assumed emergency landing and recovery scenarios is assessed with single engine
evaluation of the aircraft's landing and taxiing performance.

Technical issues and simulations are also needed to
analyze how engine and/or engine out conditions affect
the aircraft's performance during a single engine emergency landing.

Emergency Power Ratings: A 30 second emergency power rating was assumed for this
application analysis.

High Performance Configurations: New high performance configurations and related for optimum performance and
cruise speeds are readily achievable for the tiltrotor,
cruise speeds are readily achievable for the tiltrotor.
cruise speeds are readily achievable for the tiltrotor.
cruise speeds are readily achievable for the tiltrotor.
cruise speeds are readily achievable for the tiltrotor.
cruise speeds are readily achievable for the tiltrotor.

Aerodynamic Improvement: Interference drag at
decompression characteristics:
modes, including lift and drag forces, and sudden
changes concerning the mean line as well as changes in
atmospheric pressure and temperature, allowing for
composite fuselage and high-stress areas. However,
composite fuselage should be significantly no more
pressurized than typical fuselage. Pressurizing a

Other Issues:

- Fly-by-wire and multiplex bus controls
- Field inspection
- Composite manufacturing quality control
Other Issues: National Aerospace System

Current National Aerospace Systems (NAS) were reviewed in light of the tiltrotor's operational characteristics. Tiltrotors can operate in the present air traffic control (ATC) environment, but with abbreviated utilization of their operational capabilities. Summarized below are the changes in operating environment and infrastructure that would make tiltrotor shuttle service effective:

Navigation Aids. Flight procedures need to be developed to take advantage of latest radio navigation aids, especially MLS (microwave landing system). MLS spatial coverage, as shown to the right, is far superior to current ILS. MLS could allow segmented curve approaches that would allow aircraft to avoid obstacles during approach and departure. At airports, tiltrotors need to operate independently of fixed-wing traffic.

Heliports/Vertiports. New terminal instrument procedures (TERPS) are needed to support IFR operations at vertiports and VTOL instrument flight rule (IFR) operations at current conventional airports and heliports. Particularly, the present obstruction surfaces shown at right need to be modified to take advantage of advanced ATC control abilities and improved navigation aids to fully exploit the civil tiltrotor’s capabilities.

Approach and landing minimums. New low-weather minimums that take advantage of MLS and slower tiltrotor approach speeds are needed.

Cockpit displays. Lower approach and landing minimums can be supported with improved displays that show relevant terrain and obstacles.

Airways. Advanced ATC control capability and radio navigation aids can also reduce lateral, longitudinal, and vertical separations, allowing greater airway capacity.

Airports. For most effective service, tiltrotors should operate independently of fixed-wing traffic.
since these models do not have tilting engines.

Problem at all with the ATTR-1900 and CTR-7500.

nozzle mixer or deflected exhausts, and there is no
surface over time. This can be achieved with a
neutral exhaust. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
neutral. If the exhaust is too close to the ground,
Other Issues:
Technology Spinoffs

Many of the technologies used on the V-22 airplane program are being developed concomitantly with other areas of the civil and military world. Such items as advanced cockpit displays, fly by wire, variable cycle constant frequency generator systems, and advanced multiplexed data bus systems are being developed by the civil and military industry. Advancements in either improve the progress and production readiness of the other and improve performance, reliability, and efficiency of both.

The most significant of the advanced technology is incorporated in the V-22 is the extensive use of composites, offering reduced weight, increased strength, decreased fatigue, corrosion, and maintenance. To date, no commercial aircraft has used more composites than the V-22.

The chart at the right reflects how the V-22 is advancing many technologies and how these developments strengthen the efficiency and productivity of the V-22 as well as commercial transports.

Other areas where the V-22 program is pushing the state of the art are in the realm of overall airplane systems management, control and health monitoring.

Highlights of some of these advanced technologies follow:

**Thrust power management systems.** Automatic rotor speed control, drive system load protection, OEL detection and compensation, and power sharing between engines.

**Engine and Transmission Health Monitoring.** Sensors on and inside engines and transmission record the operation of critical components and store this information in the aircraft’s computer for corrective maintenance. This is a “first” for the rotorcraft industry.

**Thermoplastics.** Simplified manufacturing, reduced weight, reduced cost, reduced maintenance.

**Carbon brakes.** Lighter, more fade resistant.

<table>
<thead>
<tr>
<th>Technologies</th>
<th>767</th>
<th>V-22</th>
<th>1995 Tiltrotors</th>
<th>Potential Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composites</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>W, C, F, M</td>
</tr>
<tr>
<td>Control Surfaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empennage</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>W, C, F, M</td>
</tr>
<tr>
<td>Wing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuselage</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>W, C, F, M</td>
</tr>
<tr>
<td>Thermoplastics</td>
<td>X</td>
<td></td>
<td>X</td>
<td>M, C</td>
</tr>
<tr>
<td>High Strength Aluminum</td>
<td>X</td>
<td></td>
<td>X</td>
<td>S, W</td>
</tr>
<tr>
<td>Aluminum-Lithium</td>
<td></td>
<td></td>
<td></td>
<td>W, M, F</td>
</tr>
<tr>
<td><strong>Flight Deck</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Management System</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>L, C, M, V</td>
</tr>
<tr>
<td>Displays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cathode Ray Tube</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>C, M, V, L</td>
</tr>
<tr>
<td>Flat Panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Touch Panel</td>
<td>X</td>
<td></td>
<td></td>
<td>M, V, L</td>
</tr>
<tr>
<td>Laser Inertial Ref. System</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>M, V</td>
</tr>
<tr>
<td>Ada Software Language</td>
<td>X</td>
<td></td>
<td></td>
<td>M, C</td>
</tr>
<tr>
<td><strong>Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Bus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARINC 429</td>
<td>X</td>
<td></td>
<td></td>
<td>C, W, M</td>
</tr>
<tr>
<td>MIL 1553</td>
<td>X</td>
<td></td>
<td></td>
<td>C, W, M</td>
</tr>
<tr>
<td>DATAC (ARINC 629)</td>
<td></td>
<td></td>
<td></td>
<td>C, M, V, W</td>
</tr>
<tr>
<td><strong>Signal by Wire</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Surface</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>L, W, C</td>
</tr>
<tr>
<td>Brake/Steering</td>
<td></td>
<td></td>
<td></td>
<td>L, C</td>
</tr>
<tr>
<td><strong>Signal by Light</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power by Wire</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMA</td>
<td>X</td>
<td></td>
<td></td>
<td>C, M, V, W</td>
</tr>
<tr>
<td>EHA</td>
<td></td>
<td></td>
<td></td>
<td>M</td>
</tr>
<tr>
<td><strong>Carbon Brakes</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>C, M, W</td>
</tr>
<tr>
<td><strong>Thrust Power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management System</td>
<td>X</td>
<td></td>
<td></td>
<td>L, M</td>
</tr>
<tr>
<td><strong>Variable Speed-Constant</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Generator</td>
<td>X</td>
<td></td>
<td></td>
<td>W, M</td>
</tr>
<tr>
<td><strong>Ice Protection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice Release Paint</td>
<td>X</td>
<td></td>
<td></td>
<td>C, M, W</td>
</tr>
<tr>
<td>Ice Phobic Surface</td>
<td>X</td>
<td></td>
<td></td>
<td>C, M, W</td>
</tr>
<tr>
<td>Electro Impulse</td>
<td>X</td>
<td></td>
<td></td>
<td>W, V</td>
</tr>
<tr>
<td><strong>High Pressure Hydraulics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Code:**  
W = Weight  
M = Maintenance/Reliability  
S = Strength-to-Weight  
L = Workload (Crew)  
C = Cost  
F = Fatigue  
V = Volume
Overviews:

Increased weight, maintenance, and cost of current materials.

Emphasis on monitors and ground personnel.

Data bus: fewer independent circuits, reduced data, and increased data for pilots during flight.

Ada software: more formal and less ambiguous.

Least square systems: simpler, more dependable.

Laser Inertial Systems:

Improve stability: the Y-22 uses a single strap, and less gravity.

Model: Leesburg, special operations, less expensive, the Y-22 uses a single strap, and less gravity.

Flight decks: improved displays, color CRTs, and additional aircraft.

Alloys: new generation aluminum/Aluminum alloys.

Composites: by far the most significant Y-22.
National Issues

There are two basic forces at the national and international level that appear to have major implications for civil tiltrotor development and related national policy and planning: (1) strong global competition in aerospace market (especially as it relates to balance of trade) and (2) significant congestion in the air transportation system.

In recent years, numerous reports have appeared in the popular press and many studies and review panels have been created to address the trade deficit, now a problem of massive proportions. In 1986, the trade deficit was a record $177 billion. The aerospace industry was once one of the brightest spots in this dismal picture. But the aerospace industry's balance of trade peaked in 1981 and has been declining since. The European share of the commercial jet transport market has grown from about two percent in 1972 to more than 20 percent in 1986. In total, foreign rotorcraft manufacturers' share of the world market grew from a few percent in the 1950s to about 50 percent in 1986. Currently, total sales are depressed. The tiltrotor represents an opportunity to rejuvenate this market.

The general aviation segment of the U.S. aerospace industry has all but collapsed. Between 1975 and 1980, as many aircraft were shipped in a single month as were shipped in all of 1986.

There is a generally acknowledged narrowing of American technological leadership in electronics, aerospace, and other areas that were exploited in the past. In 1986, for the first time, overall imports of high technology exceeded exports.

The growth and changes in air traffic and related systems are also generally known and well understood. Clearly, one of the most visible issues in the wake of growing air traffic, hub and spoke operating systems, and related airline deregulation is congestion and delay at major airports. Across the board, flight delays are up.

Helicopters

The previously cited (Introduction) "National Aeronautical R&D Goals, Agenda for Achievement" presented by the Presidents Office of Science and Technology specifically discusses tiltrotor aircraft and concludes that their capabilities should be considered for intercity transportation.

<table>
<thead>
<tr>
<th>Airport</th>
<th>Delays Per 1000 FLTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newark (New Jersey)</td>
<td>143</td>
</tr>
<tr>
<td>LaGuardia (NYC)</td>
<td>88</td>
</tr>
<tr>
<td>John F. Kennedy (NYC)</td>
<td>75</td>
</tr>
<tr>
<td>Logan (Boston)</td>
<td>74</td>
</tr>
<tr>
<td>San Francisco</td>
<td>61</td>
</tr>
<tr>
<td>O'Hare (Chicago)</td>
<td>51</td>
</tr>
<tr>
<td>Hartsfield (Atlanta)</td>
<td>50</td>
</tr>
<tr>
<td>Minneapolis-St. Paul</td>
<td>43</td>
</tr>
<tr>
<td>Washington National (D.C.)</td>
<td>34</td>
</tr>
<tr>
<td>St. Louis</td>
<td>34</td>
</tr>
<tr>
<td>US Average</td>
<td>39</td>
</tr>
</tbody>
</table>

Source: FAA Statistics for Jan-Sept. 1986, as Quoted in USA Today, 11/17/86
## Further Reading

Listed below is a selection of articles and publications that provide a cross-section of information about the civil tiltrotor and related subjects.


National Business Aircraft and University of Virginia, A Study of Business Aviation In 1985, University of Virginia, 1985.
