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Civil Tiltrotor Missions and Applications: A Research Study

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

Study Team - **Boeing Commercial Airplane Co.**
Bell Textron
Boeing Vertol
NASA ARC (Study Management)

For:
FAA/NASA/DOD

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Sponsored By

Federal Aviation Administration
National Aeronautics and Space Administration
Department of Defense

Government Executive Steering Group

FAA	NASA	DOD
Craig Beard (Chair)	John Burks	William Schaefer
Larry Andriesen	Ray Whitten	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

Teamed 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.

Contents

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

Recommendations:

Develop a National Plan for a tiltrotor transportation system, including:

Civil Tiltrotor Technology Development

- Reduce risks and costs through design concepts, materials, and production methods.
- Optimize aerodynamics and configurations.
- Validate key technologies.
  - Canard configuration
  - Pressurized composite fuselage
  - Rotor/wing interaction

Infrastructure Planning and Development

- Vertiports conveniently located in metropolitan areas.
- New terminal instrument procedures to take advantage of precision navigation equipment.
- Integration into the National Aerospace System.
- Certification criteria for powered lift.
  - Continued development of airworthiness criteria

Flight Technology Demonstration Plan

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

Near-term Actions

- Continue FAA/NASA/DOD/Industry cooperation for civil tiltrotor development.
  - Follow-on work on civil tiltrotor technology development
  - Work on infrastructure and flight demonstration development plans
- Key civil tiltrotor development to V-22 program.

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.

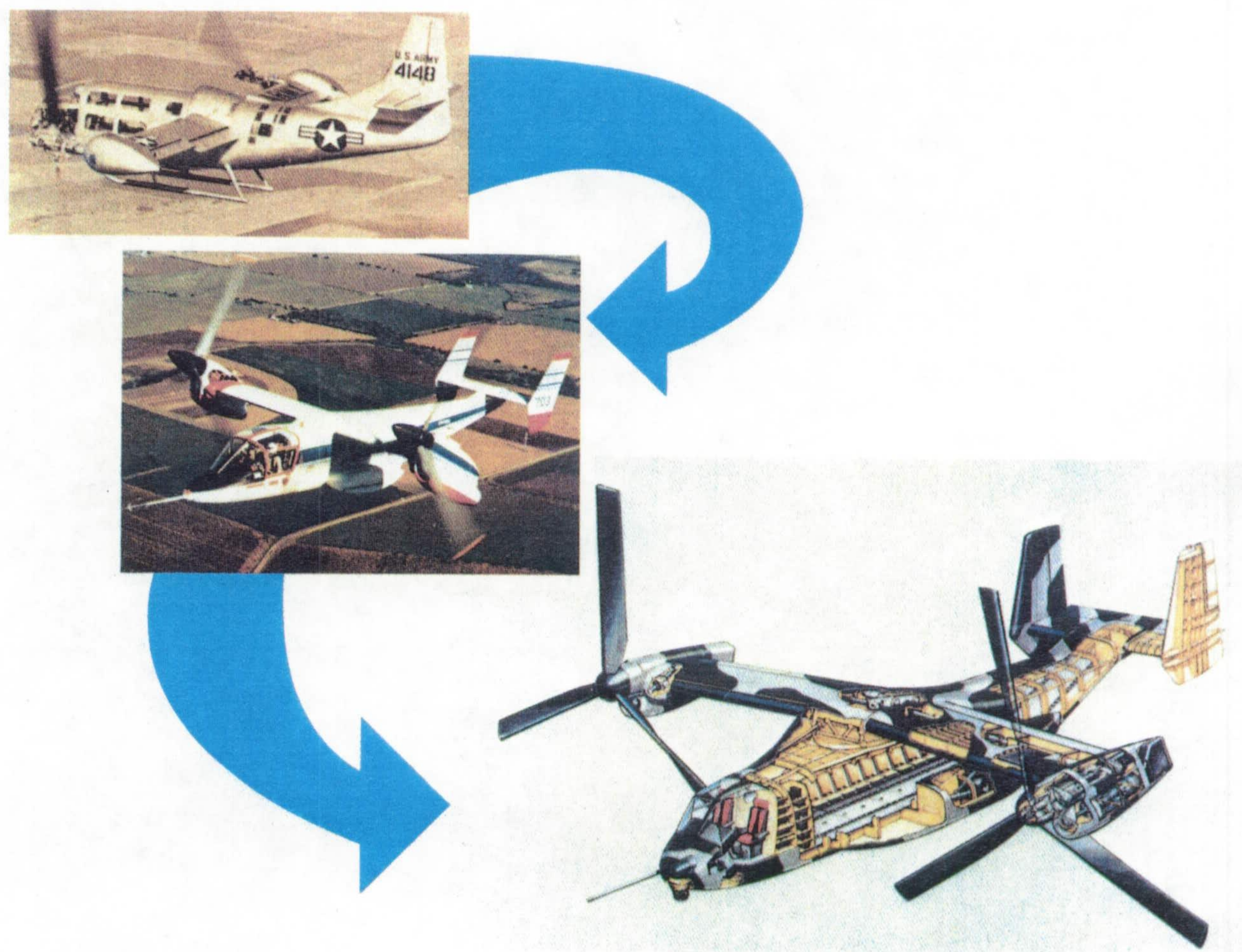
Funded by NASA and the Army, the XV-15's have accumulated more than 800 hours of testing, and they continue to serve as testbeds to refine tiltrotor concepts, prove new components and systems, and demonstrate the controllability, performance, and community compatibility of tiltrotors.

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



Thirty Years of Tiltrotor Progress

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:

I - Candidate Market Requirements: potential markets and their operational and design requirements.

II - Aircraft Functional Characteristics: tiltrotor configurations and performance characteristics.

III - Facility Requirements: ground facilities needed for viable civil tiltrotor operation.

IV - Operational Analysis: operations of different configurations in each candidate market. Also, impact of higher cruise speeds.

V - Economic Evaluation: investment costs, cash operating costs, operator profitability.

VI - Technology Spinoffs: V-22 technologies and how they can be used in other applications.

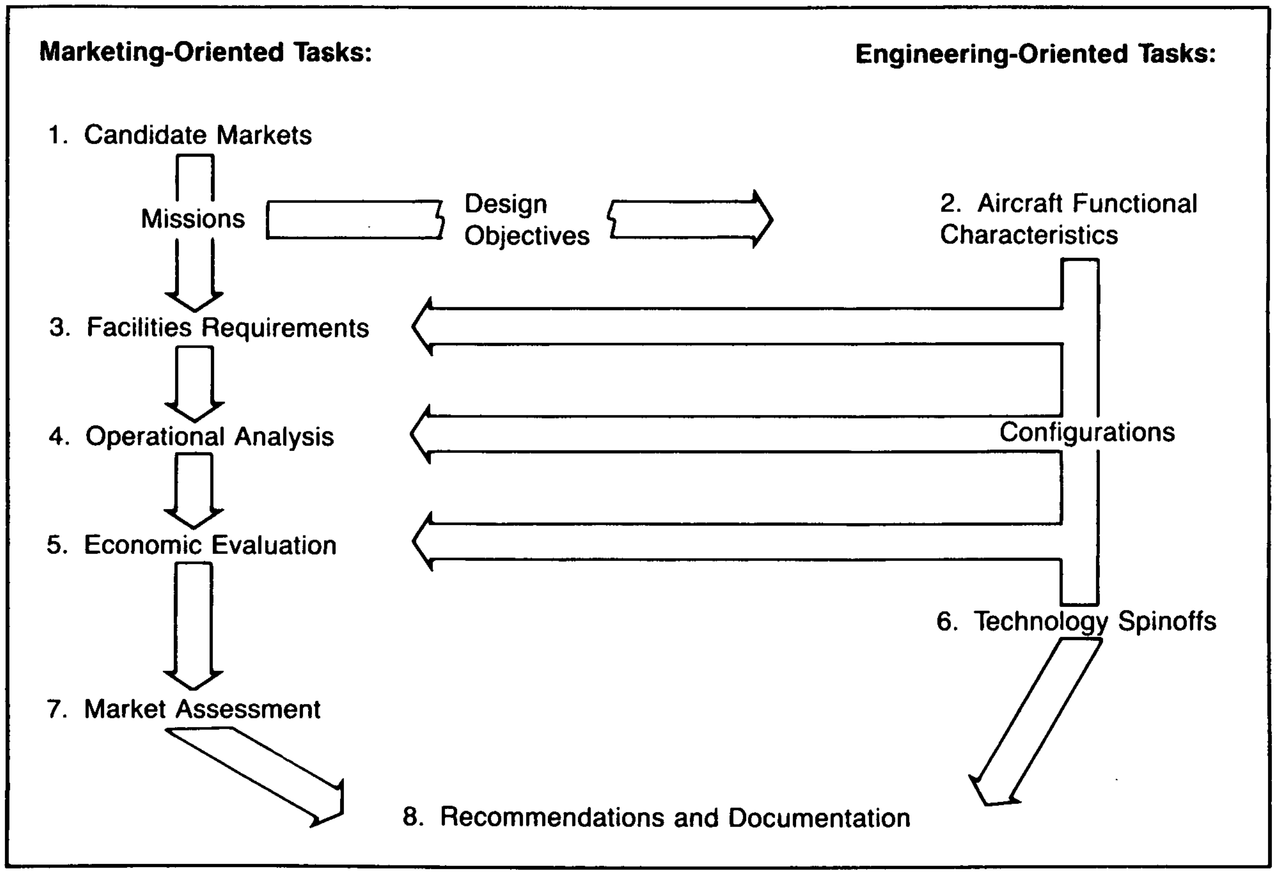
VII - Market Assessment: tiltrotor penetration of candidate markets. Critical tiltrotor features needed.

VIII - 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.



Civil Tiltrotor Study Process

Government Executive Steering Group

FAA	NASA	DOD
Craig Beard (CHR)	John Burks	Bill Schaefer
Larry Andriesen	Ray Whitten	LTC Lou Herrick

NASA ARC
J. Zuk - Study Director
C. McKeithan - Study Manager
T. Galloway - Tech. Monitor

Executive Council

Boeing Commercial	Boeing Vertol	Bell Helicopter
R. Albrecht	J. Mallen	J. Horner
C. Longridge		

Management Committee

Boeing Commercial	Boeing Vertol	Bell Helicopter
C. W. Clay (Study Manager)	S. Mayer	R. Reber

Team

Boeing Commercial	Boeing Vertol	Bell Helicopter
P. Baumgaertner (Eng)	D. Balzer (Eng)	L. Balchunas (Fin)
C. Carpenter (Eng)	F. Bergnen (Mkt)	D. Cannon (Eng)
J. Foster (Eng)	R. Gabel (Eng)	J. Dubon (Mkt)
B. Goben (Fin)	B. Hazlett (Eng)	W. Joiner (Eng)
A. Hoshino (Mkt)	Z. Jasnoff (Fin)	P. Leslie (Fin)
M. Jahnke (Eng)	J. Kennedy (Mkt)	G. Marr (Eng)
B. Lee (Mkt)	S. Mayer (Mkt)	R. Reber (Mkt)
G. Nihart (Eng)	G. Sherwin (Eng)	W. Sirota (Eng)
B. Norwood (Mkt)	J. Wilkerson (Eng)	R. Spivey (Mkt)
J. Thomas (Mkt)	M. Wilt (Eng)	R. Taylor (Eng)
P. Thompson (Mkt)	D. Woodley (Eng)	
D. Underwood (Mkt)	D. Wu (Mkt)	

Organization of Study Team

Organization

Because of the broad interest by industry and government in this study, a government steering committee and a company executive council were established; both met frequently. Their functions were to monitor progress and ensure effective communication of conclusions.

The organization of the tiltrotor study team is displayed to the left; general functional area responsibilities (marketing, engineering, finance) are indicated.

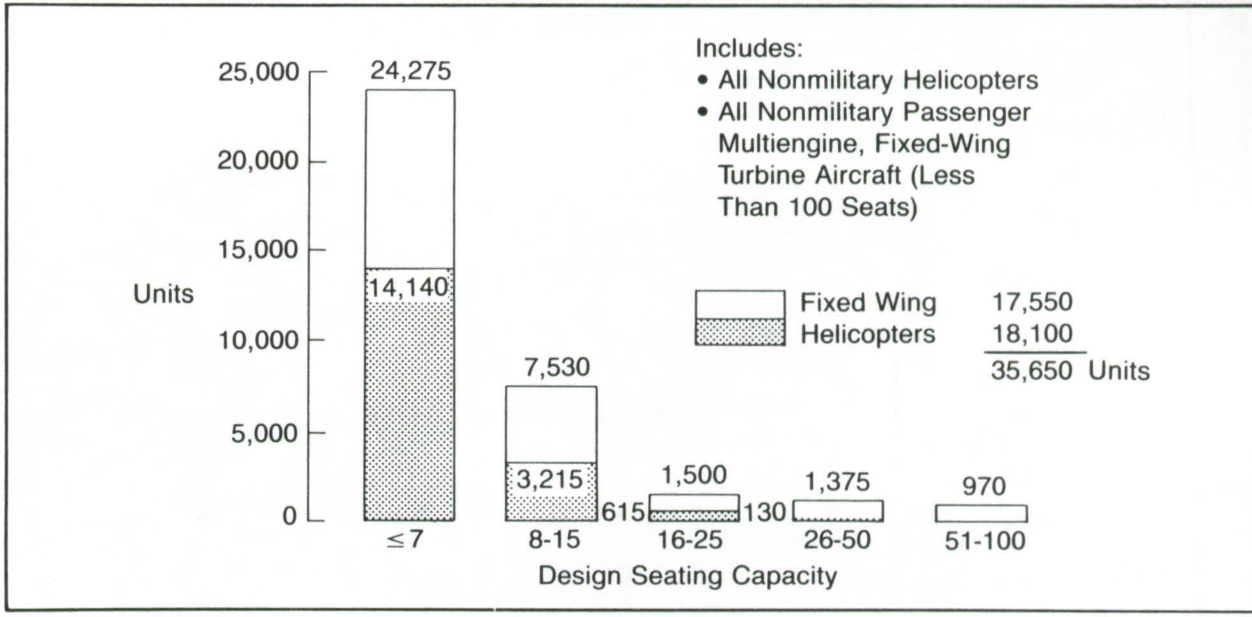
Boeing Commercial Airplane Company (BCAC) was designated as contract lead and provided study team management and marketing management. Boeing Vertol and Bell Helicopter provided technical and marketing input. NASA Ames Research Center was in overall charge and provided guidance and direction to the study team through coordination meetings and correspondence.

The study was broad in scope. Because of the breadth of topics examined, several could not be examined in detail and are proposed for further, more detailed, analysis.

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:

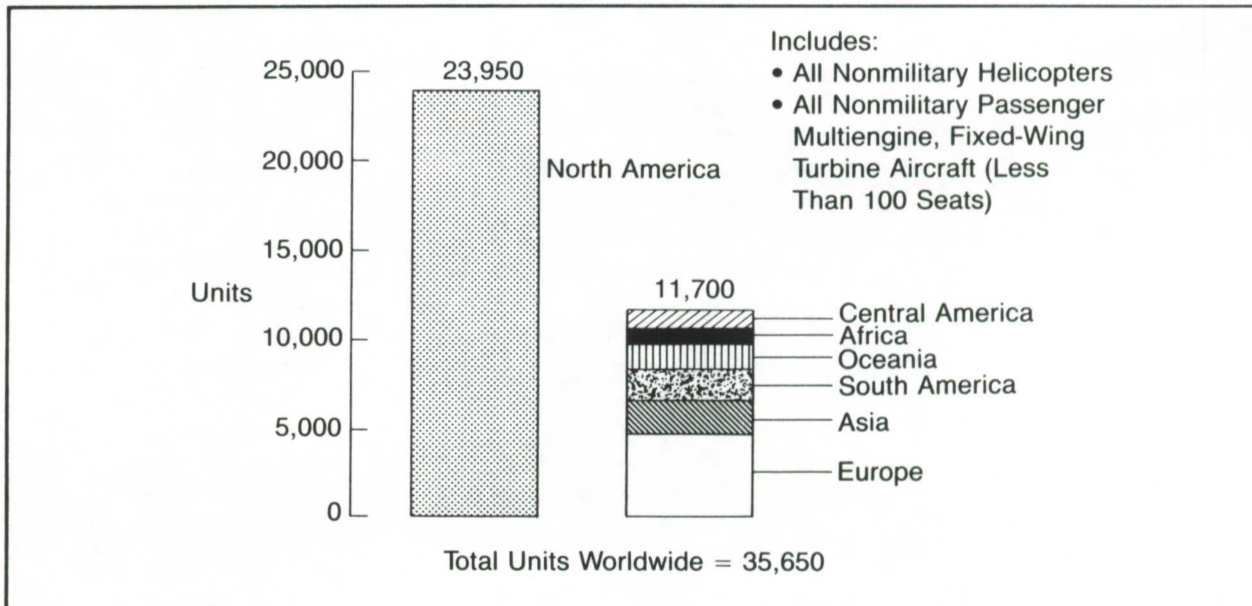
- a survey of prospective users, to identify their needs.
- an extensive review of previous studies, to place the civil tiltrotor in historical perspective.
- examination of existing inventories of fixed-wing and helicopter aircraft, from standpoint of size, range, and geographic distribution, to identify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



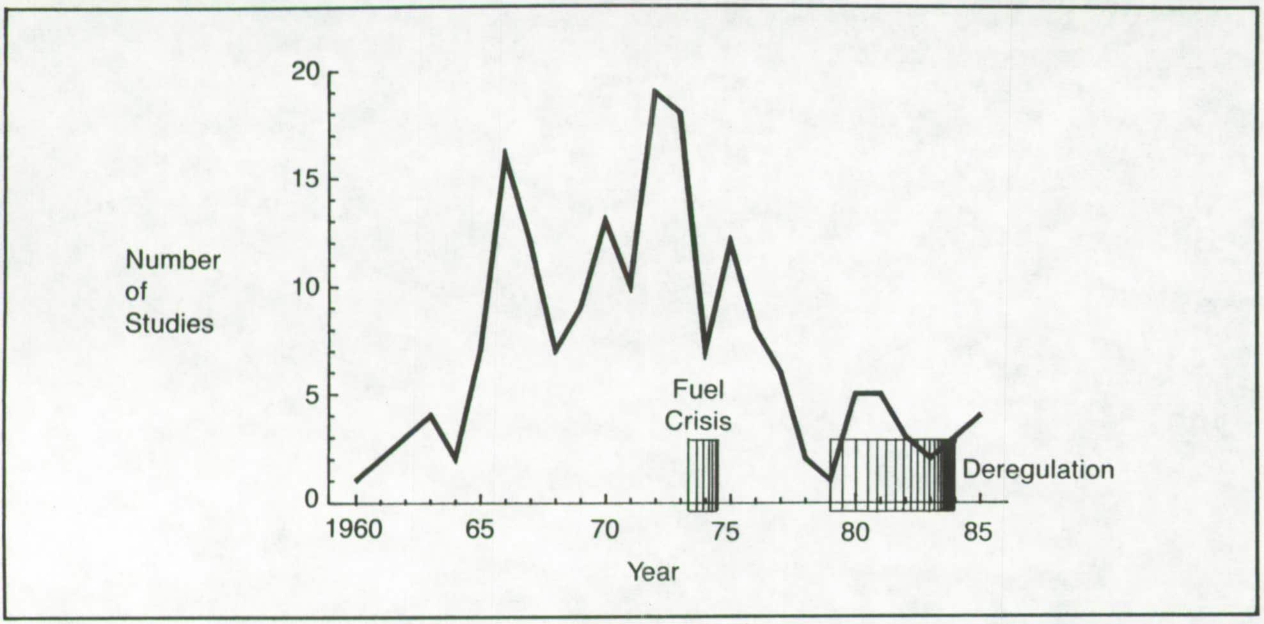
Existing Inventory (Size Distribution)

User Groups	Vehicle Applications
• Corporate/ Executive • Comm. Operators • Civil Government • Offshore Oil • Other	• High Density Passenger • Cargo/Package Express • Developing Region • Resource Development • Corporate/ Executive • Public Services
Surveys • Bell/Vertol/Aerospatiale/This Study • 312 Potential Users	

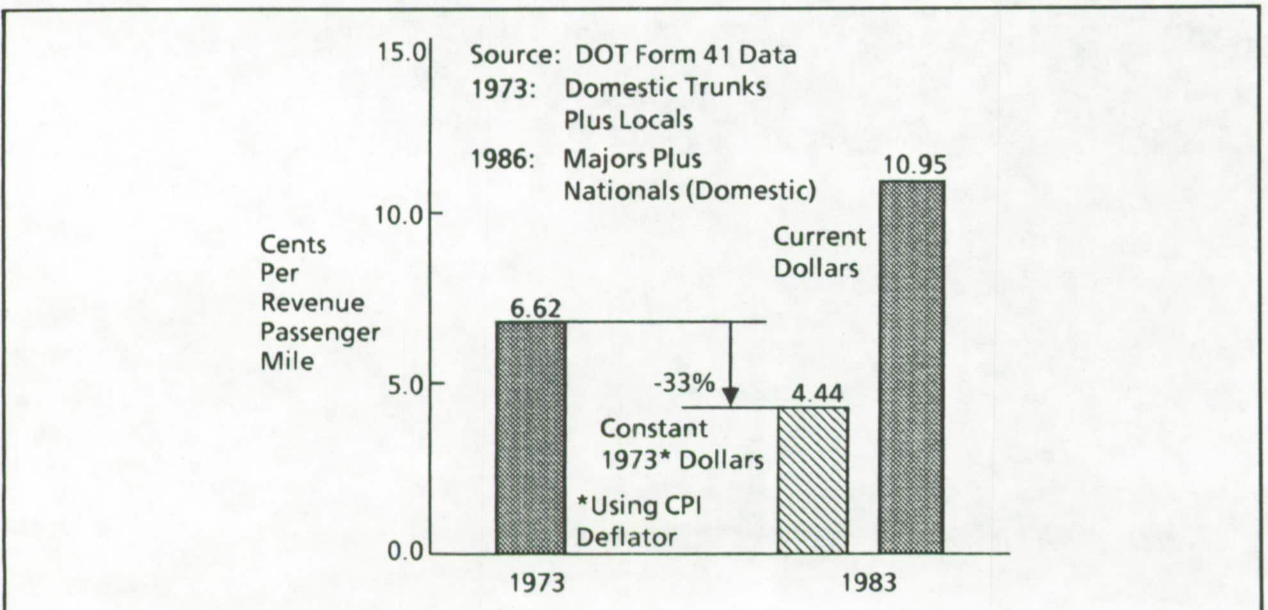
Market Surveys



Existing Inventory (Geographical Distribution)



V/STOL Studies (1960 to 1985)



Decline in Fare Revenues

Candidate Markets (continued)

A number of government and industry studies performed before the 1973 fuel crisis addressed the role of V/STOL aircraft in improving regional transportation systems. With the fuel crisis—and government funding being directed toward aircraft fuel efficiency—the number of V/STOL studies declined. While this study addresses markets that have been evaluated previously, it does so from the perspective of the current environment: deregulation, high fuel costs, declining fares.

Inputs were consolidated into a set of design objectives that formed the basis of the configuration development discussed later.

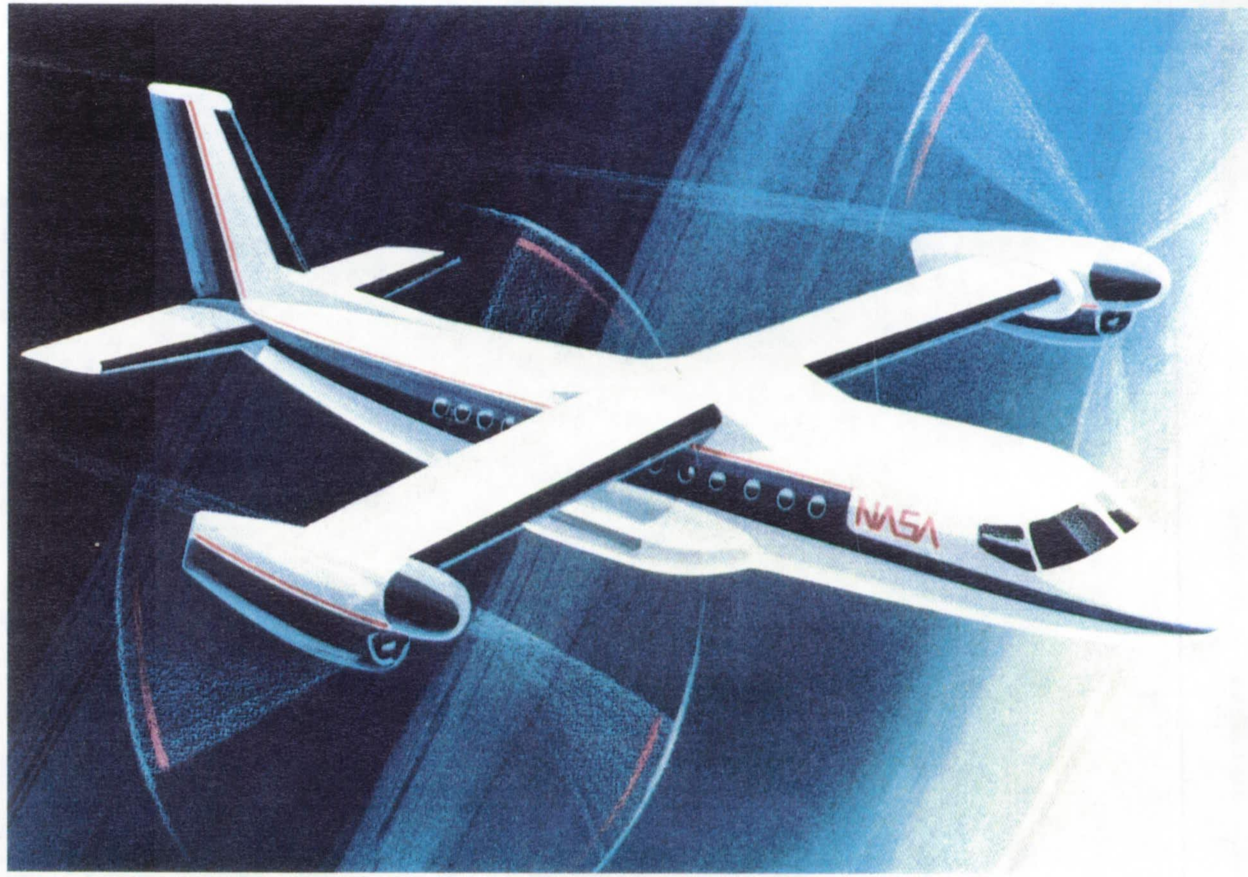
The approach used—working from market requirements, through design, to a market assessment—simplified problems to basic components: the physical and operational features important for strong market acceptance and the economic level required to achieve competitive viability of the new civil tiltrotors.

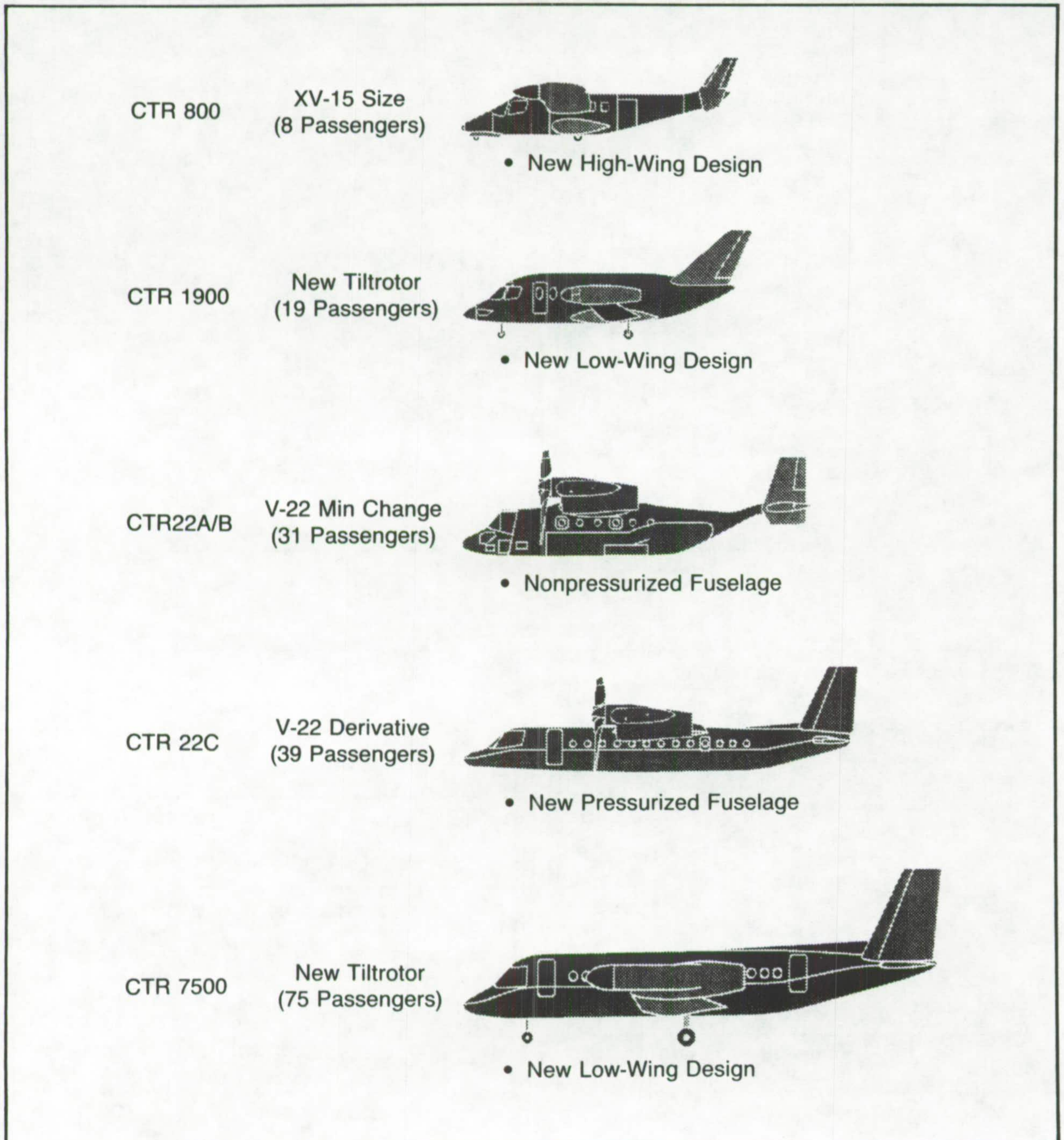
The BCAC, Bell and Vertol, working agreement with NASA reflected this philosophy; the team would:

". . .determine where tiltrotor makes sense. . .show how it makes sense. . .explain what it takes to make it commercially attractive. . ."

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





Tiltrotor Configurations

Civil tiltrotor configurations developed for the study are shown to the left. One configuration, the CTR-800, is based on the XV-15 tiltrotor size; two configurations, the CTR-22A/B and CTR-22C, are derivations of the V-22 military tiltrotor; and two configurations, the CTR-1900 and CTR-7500, are all-new civil tiltrotors. An additional derivative of the military V-22 tiltrotor, the CTR-22D, was developed to evaluate higher capacity and a more efficient fuselage cross-section.

The design technology of the V-22 military tiltrotor drove the preliminary design of all the configurations. Guidelines for civil tiltrotor design were developed by BCAC, Bell, and Vertol based on V-22 and commercial design experience. Specific modifications were based on federal aviation regulations and input from commercial operators.

The structural design concept and propulsion systems used on all the configurations are the same as the V-22 military tiltrotor; these include the twin-engine arrangement, rotors, controls, gearboxes, and driveshaft cross-shafting. Some modifications were needed, depending on the location of the auxiliary power unit and whether a high or low wing was used.

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.

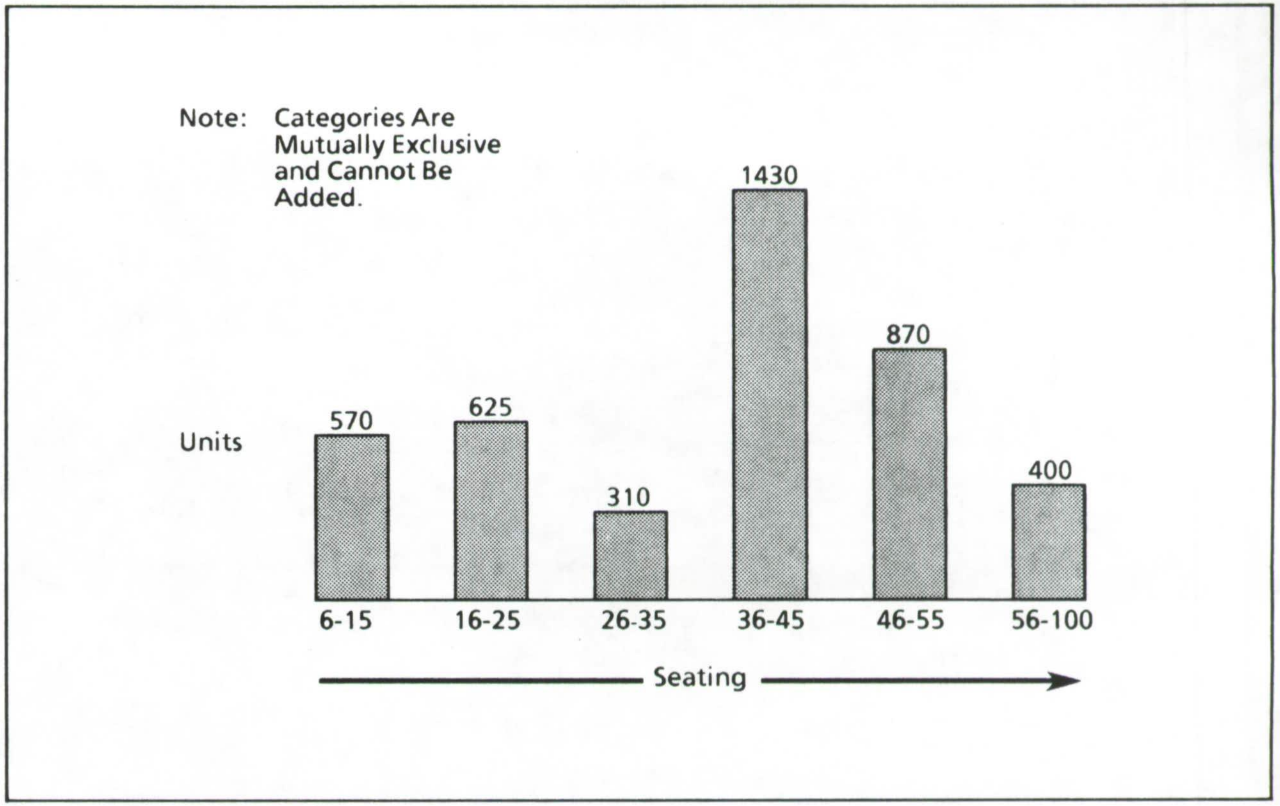
The civil tiltrotor is superior to multi-engine helicopters in most conditions, in performance as well as cost. Specific design studies for lower construction and operating costs are required to assure maximum viability in the civil marketplace.

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

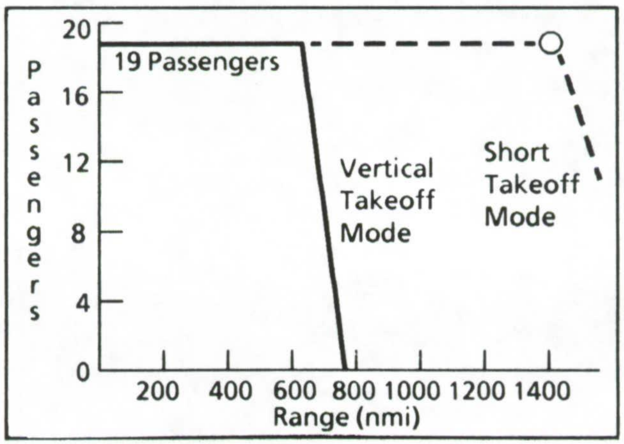
Six tiltrotor configurations were analyzed, including three V-22 derivatives. Several important conclusions were reached about the configurations. V-22 derivatives with new pressurized fuselages and modest engine growth can meet the 600 nmi design range and carry over 50 passengers. Additional capacity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



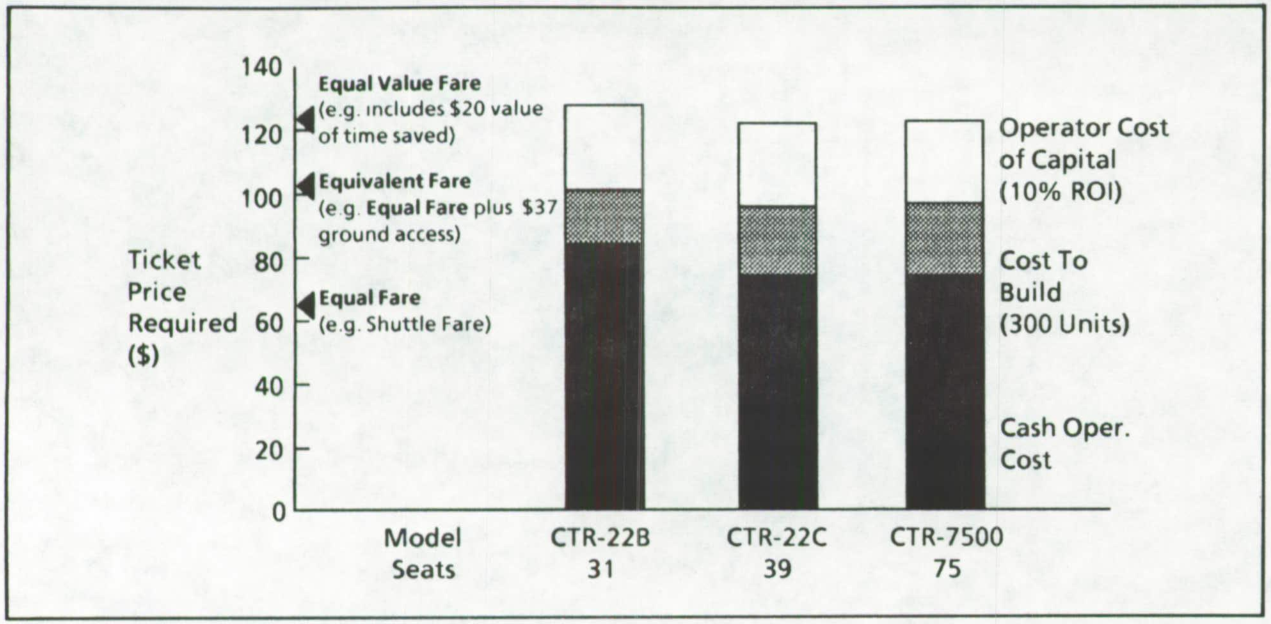
Potential Market Demand (Year 2000)



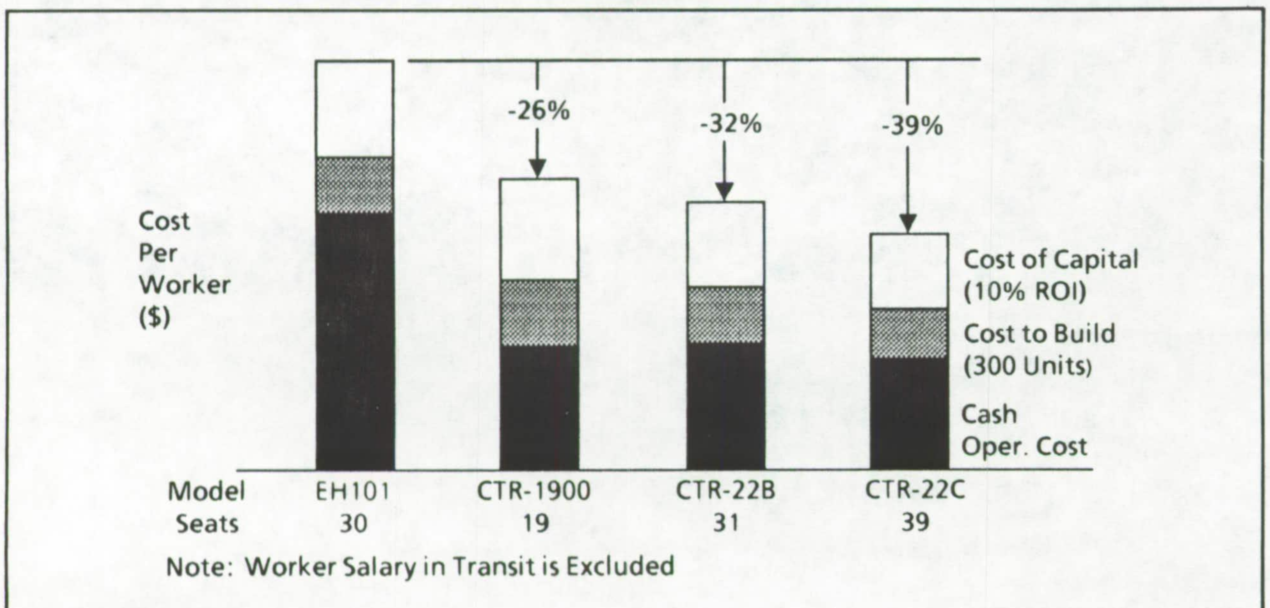
Payload Range (CTR 1900)

Mission	Demand
• High Density	• 400 to 1200
• Corporate/Executive	• 175 to 475
• Resource Development	• 85 to 325
• Cargo/Package Express	• 80 to 120
• Low Density/Developing Region	• 20 to 85
• Public Service	• 35 to 75

Potential Market Application (Year 2000)



Ticket Price Required—High-Density Market (NYC/BOS Example)



Crew Transportation Cost—Resource Development (North Sea Example)

Study Results (continued)

High-Density Market. Tiltrotors could capture 1/3 to 2/3 of the high-density, short-haul air travel market; however, ticket price may be higher to include ground transportation and/or surcharge for time saved. The key to tiltrotor acceptance is the reduction of portal-to-portal trip time, minimizing the time and expense of the ground segments of the trip, and avoiding time-consuming airport/airway congestion. This requires the use of VTOL capability at one or both ends of the trip. Tiltrotor service will attract principally business travelers.

Corporate/Executive. Tiltrotor offers great advantages in this market: operational flexibility, comfort, convenience, security, speed.

Resource Development (offshore oil). Tiltrotor economics are clearly superior to helicopters in this market. The substantial time-savings advantages of tiltrotor become even more important as resource development moves farther offshore.

Cargo/Package Express. Tiltrotor's low noise and VTOL capability are well-suited to nighttime express operations in metropolitan business centers. Economic justification will be difficult if the industry's traditionally low aircraft utilization rate also applies to tiltrotors.

Low Density/Developing Region. A broad spectrum of opportunities exist. Governmental support of startup and operation is likely to be required. A "quick-change" capability (passenger to cargo to passenger) would add to market adaptability.

Public Service. A wide range of missions were identified. In most cases, the two smaller tiltrotors would be the vehicles of choice. The minimum change version of the V-22 (CTR-22B) is also well-suited for some applications.

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.

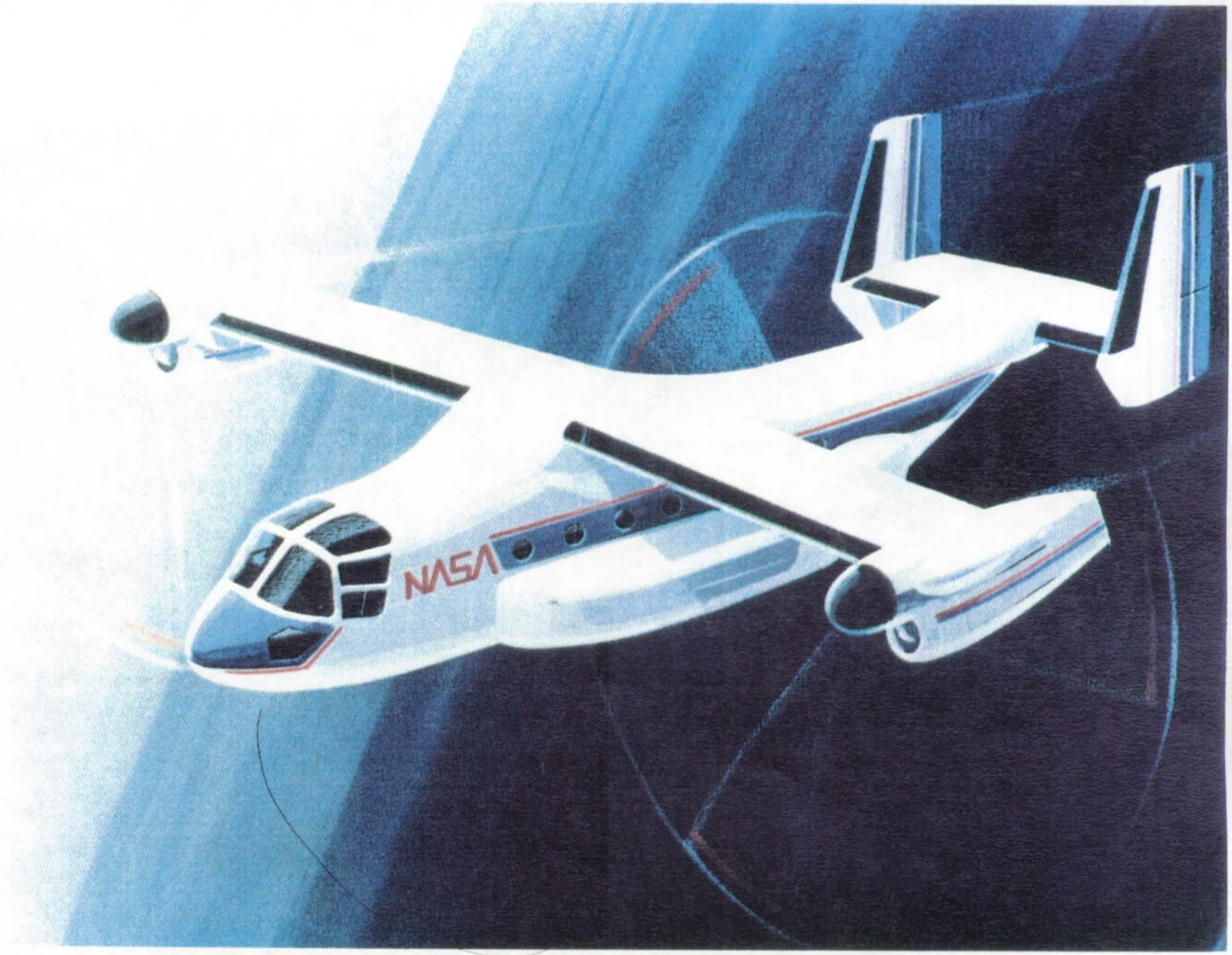
To the passenger on a portal-to-portal trip, the system needs to be perceived as accessible, safe, affordable, and convenient. Costs must be economically justifiable in terms of the value of time saved and the ease of making the entire trip.

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.



Recommendations: Design Improvements

Additional civil tiltrotor configuration analysis needs to be done to optimize performance and improve economic efficiency. Refinement of the most promising sizes (50 seats or more and 20 seats or less) needs to be expanded. Tradeoffs need to be done on three-abreast versus four-abreast fuselages, considering optimum fuselage design and V-22 wing compatibility. Canard/rotor/wing interactions need further study and wind tunnel analysis to determine controllability and airflow interactions. Engine arrangements with more than two engines need to be explored and the interrelationship between operational and certification standards understood. Finally, the design needs to be studied to optimize production, weight, drag, and ride comfort.

Design improvement studies should be conducted based on commercial requirements in order to reduce investment and operating costs. Fuselage and wing design, materials, and manufacturing techniques need to be addressed. The V-22 wing is designed to military requirements, for example, which dictates bladder cells and ballistics tolerance. Commercial designs carry fuel in wet wings.

As stated in the previously cited "National Aeronautical R&D Goals" there are highly constructive synergies that can be brought into play to effect better affordability. For example, military advances stress improved performance and combat survivability. Commercial developments, on the other hand, tend to emphasize lowered production costs, improved vehicle operational efficiencies, and increased aircraft availability with lowered maintenance costs—all of which are also attributes vital to the quest to reduce military costs. This close interrelationship of military and civil enterprise should be viewed and used as a strong positive force for operational progress, particularly to achieve affordability.

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 OEI 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.

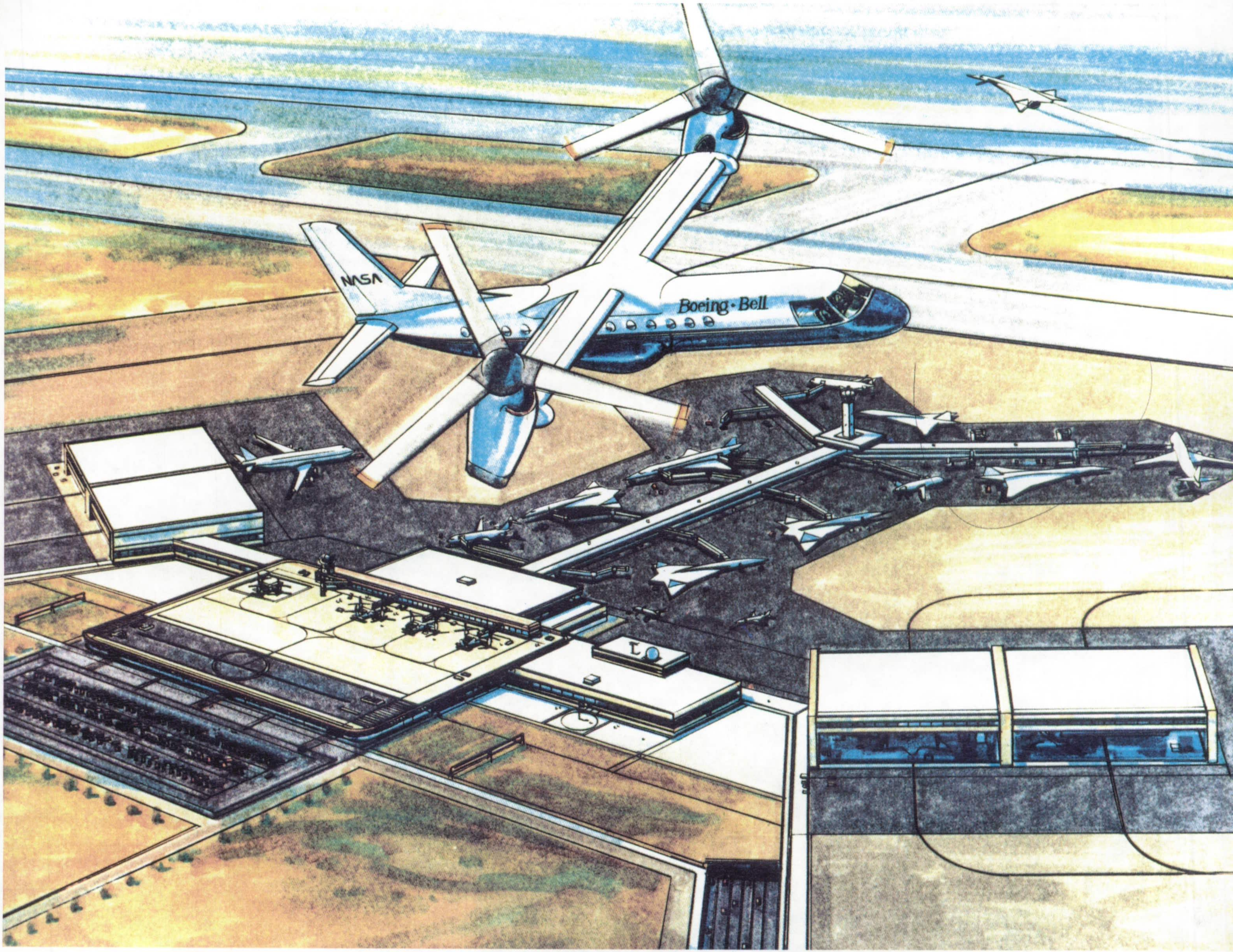
The cost of a demonstration program, while significant, is low compared to the public benefits anticipated and the value of reduced technological risk. It would be an inexpensive contribution toward long-term solutions of several national issues:

- 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.

Study Elements


NASA
Boeing·Bell

Configurations: Overview

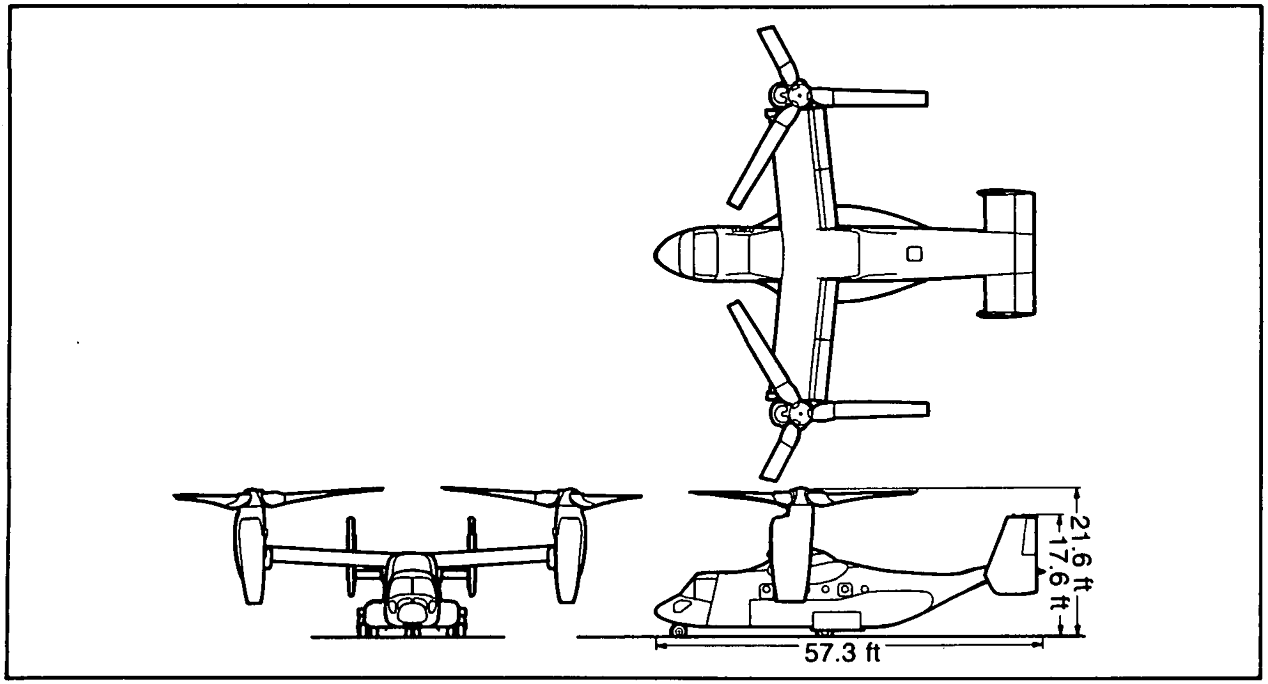
Configurations were developed to meet the study's design objectives. A summary of analysis follows:

Derivative Designs:

- The minimum change V-22 (CTR-22B) provides seating for 31 passengers and includes typical amenities (lavatory, galley, baggage, etc.). To achieve the 600 nmi design range, the V-22 transmission is uprated for higher horsepower. The CTR-22A does not meet the civil design range requirements (OEI hover takeoff and IFR reserves).
- The CTR-22C uses the V-22 wing and propulsion system and a new pressurized fuselage to carry 39 passengers for 600 nmi, without engine growth. The CTR-22D expands the CTR-22C's 3-abreast fuselage to 4-abreast to hold 52 passengers. Fully loaded, the CTR-22D's range is 280 nmi. With increased gross weight and approximately 15% increased engine thrust, the 600 nmi range requirement can be met with 52 passengers.

"All-New" Designs:

- The CTR-800 is approximately the same physical size as the XV-15. A 600 nmi range is achieved with 8 passengers in an executive interior. The fuselage is pressurized and uprated RTM322 engines are used.
- The CTR-1900's all-new design is the result of a trade study comparing the V-22 configuration (high-wing, "H" tail) and new configurations (low-wing, conventional tail and low-wing, "V" tail, canard). The CTR-1900 with the "V" tail and canard had the lowest drag and weight.
- The CTR-7500 is the largest configuration studied. 75 passengers are carried, 5-abreast. The largest projected growth version of the T406 engine is used. Additional study is needed to optimize the propulsion system design.



CTR-22A/B

	CTR-800	CTR-1900	CTR-22B	CTR-22C	CTR-22D	CTR-7500
No. Passengers	8	19	31	39	52	75
Overall Length (ft)	41.5	46.6	57.3	68.6	71.7	83.7
Wing/Rotor Span (ft/ft)	32.2/26.0	37.0/28.0	45.8/38.0	45.8/38.0	48.0/38.0	63.0/46.0
TOGW (OEI Hover) (lb)	15,750	22,800	45,120	46,230	49,260	79,820
Cruise Speed (kt)	273	283	240	282	282	300
Range (nmi) (OEI Hover)	600	637	600	600	280*	600
Engine	RTM 322 + 14%	Scaled RTM 322	T406	T406	Growth T406	Growth T406
Takeoff Engine Rating (HP) 30 sec Emergency Rating (HP)	2100 2625	3440 4300	6805 8506	6805 8506	7312 9140	12,883 16,100

* 600 nmi with 39 passengers

Characteristics

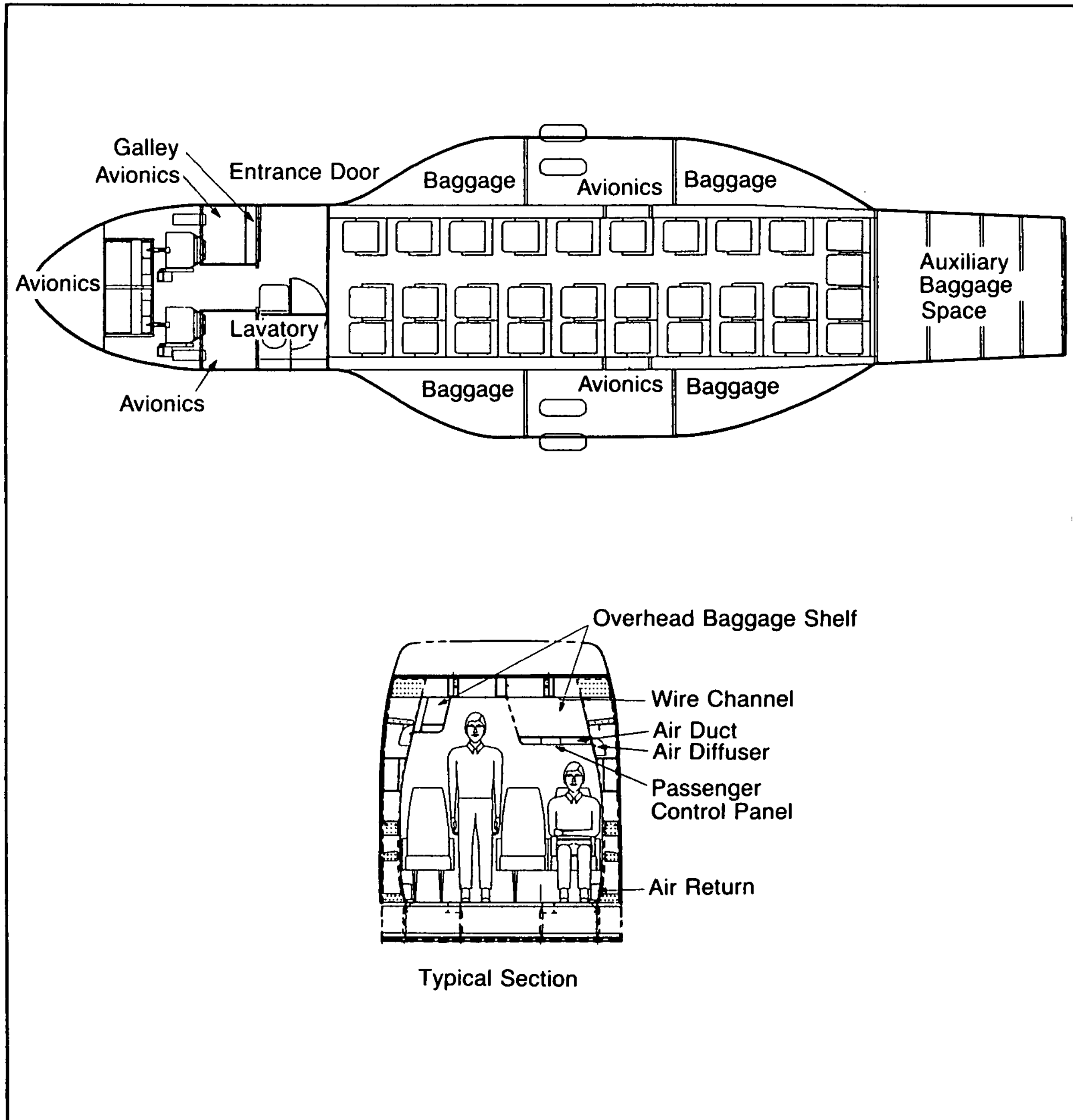
Configurations: Derivative Designs

V-22 military tiltrotor derivatives are those in the CTR-22 series (A, B, C, D). The CTR-22A/B are minimum change configurations and retain the V-22 drivetrain and primary structure. All military equipment, including cargo ramp, is removed; a passenger interior with three-abreast seating, lavatory, galley, and windows and doors is added.

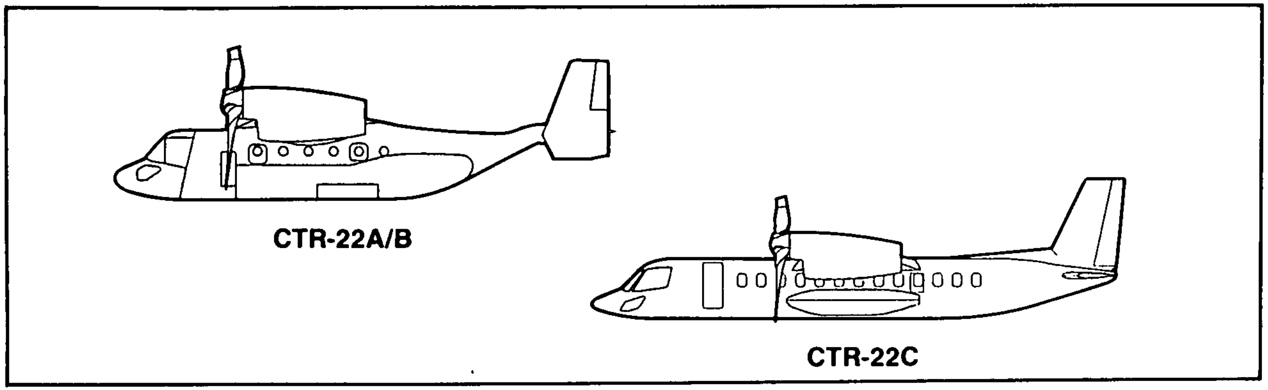
The CTR-22B is the CTR-22A with uprated transmission. The design range that results is 600 nmi. Like the CTR-22A, the CTR-22B carries 31 passengers in an unpressurized fuselage.

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. Passengers are seated three-abreast, and luggage is carried inside the fuselage rather than in the outboard sponsons of the CTR-22A/B.

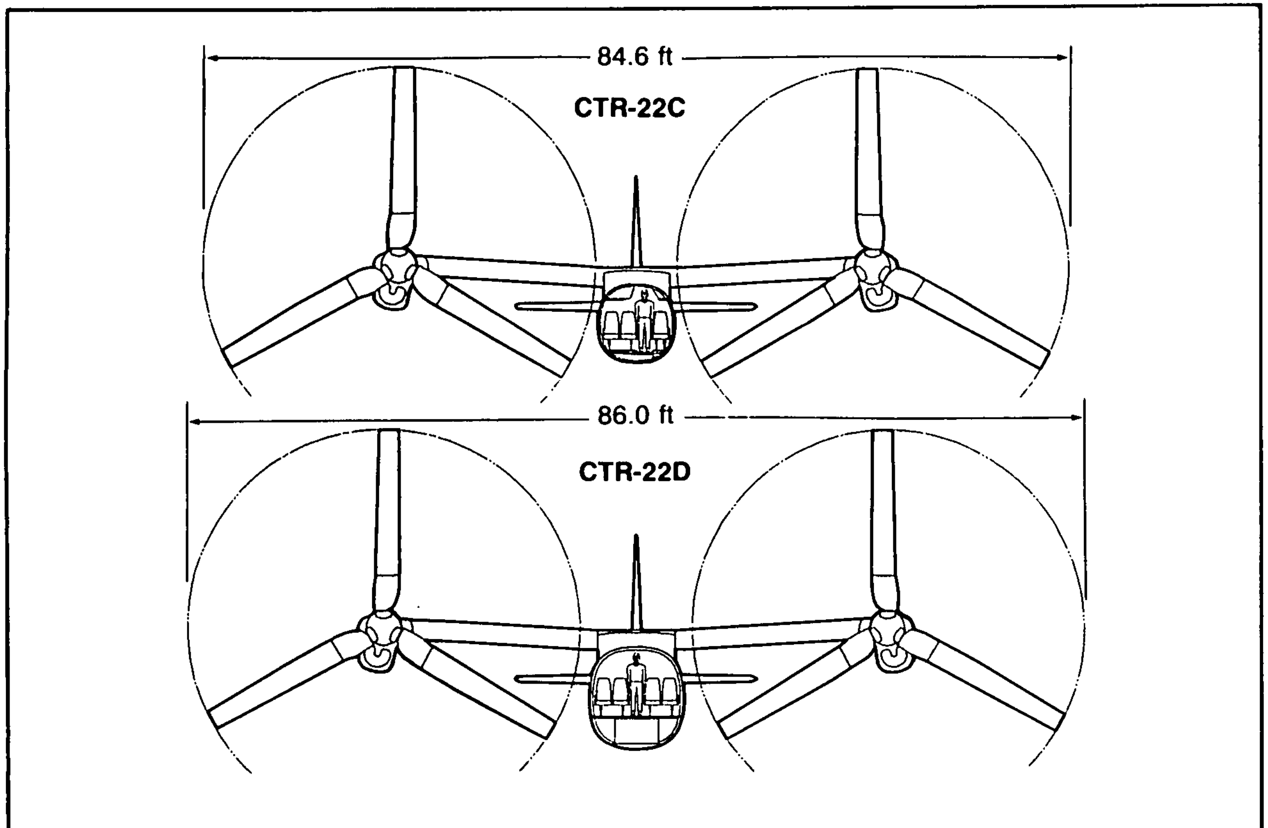
The CTR-22D expands the CTR-22C to a larger four-abreast fuselage that seats 52 passengers. With 39 passengers aboard (like the CTR-22C), the 600 nmi design range is achieved. With a full load of 52 passengers, the range drops to 280 nmi. Because of the wider fuselage, the V-22 center wing section is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



CTR-22 A/B (V-22 Minimum Change)



Comparison



CTR-22C and D

Configurations: "All-New" Designs

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

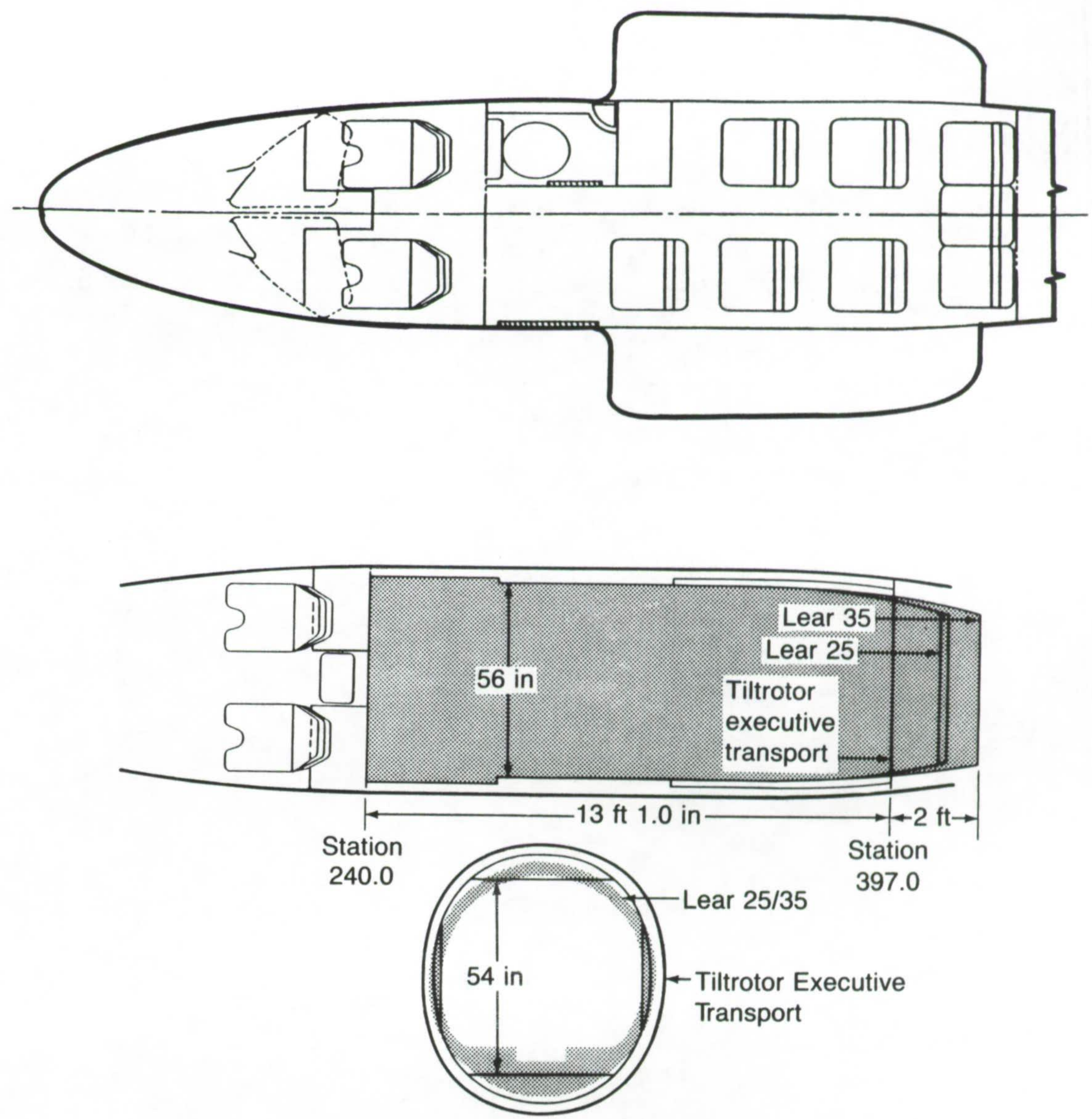
- The CTR-800, an 8-passenger executive tiltrotor with XV-15-type configuration and similar physical size.
- The CTR-1900, a 19-passenger model with a low wing, canard, and "V" tail.
- The CTR-7500, a 75-passenger model with low wing and conventional tail.

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.

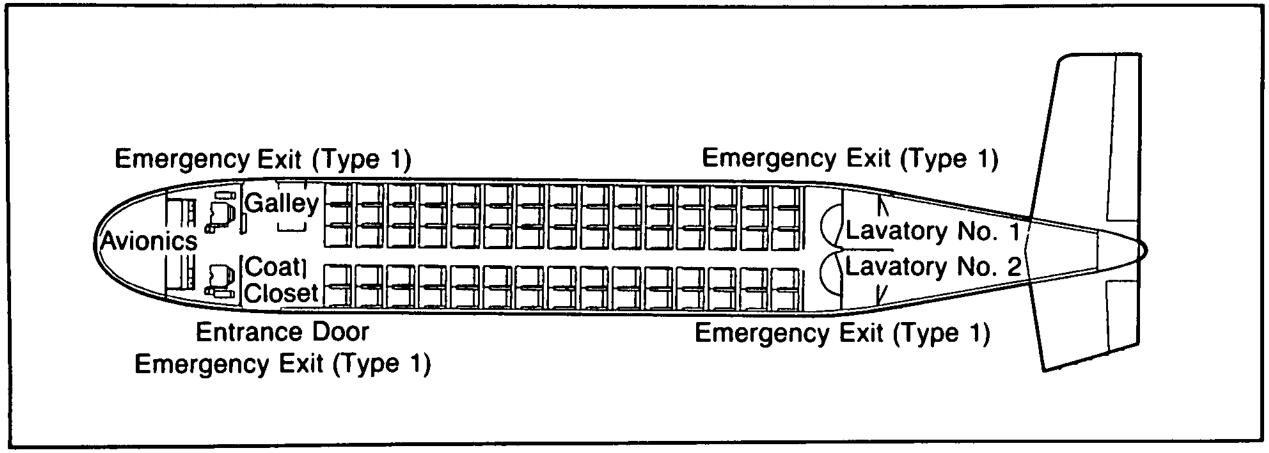
The CTR-800 is a design for corporate/executive use, with appropriate accommodations for seating 8 passengers. In cross-section, the CTR-800 is larger than the Lear Jet.

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.

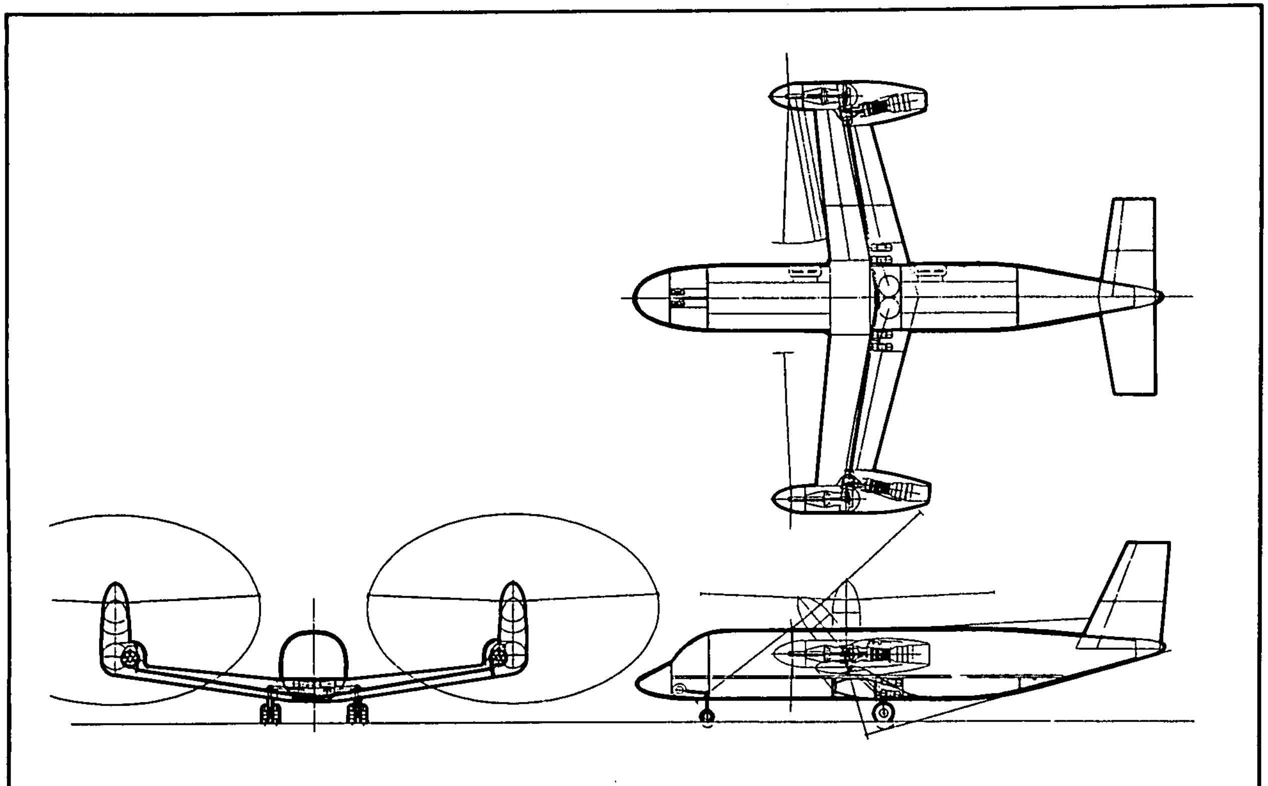
The CTR-7500 carries 75 passengers in a five-abreast configuration. An alternate design would carry the same number of passengers in a six-abreast arrangement. Again, additional study is needed to determine the optimum fuselage and the tradeoffs involved in the two-engine design versus designs using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



CTR-800



CTR-7500



CTR-7500 Drive System

Neither the CTR-1900 nor the CTR-7500 use tilting engines; because of the low-wing arrangement, only the main rotor assemblies rotate for vertical takeoff and landing. The engine thrust component is therefore lost during vertical flight, but certain advantages also accrue. A continuous wing torque box beneath the main transmission and engine is used, and the main transmission gearboxes are interchangeable between sides—for commonality. Additionally, exhaust is vented rearward, eliminating potential damage to runway and taxiway surfaces.

Configurations: V-22 vs. "All-New" Designs

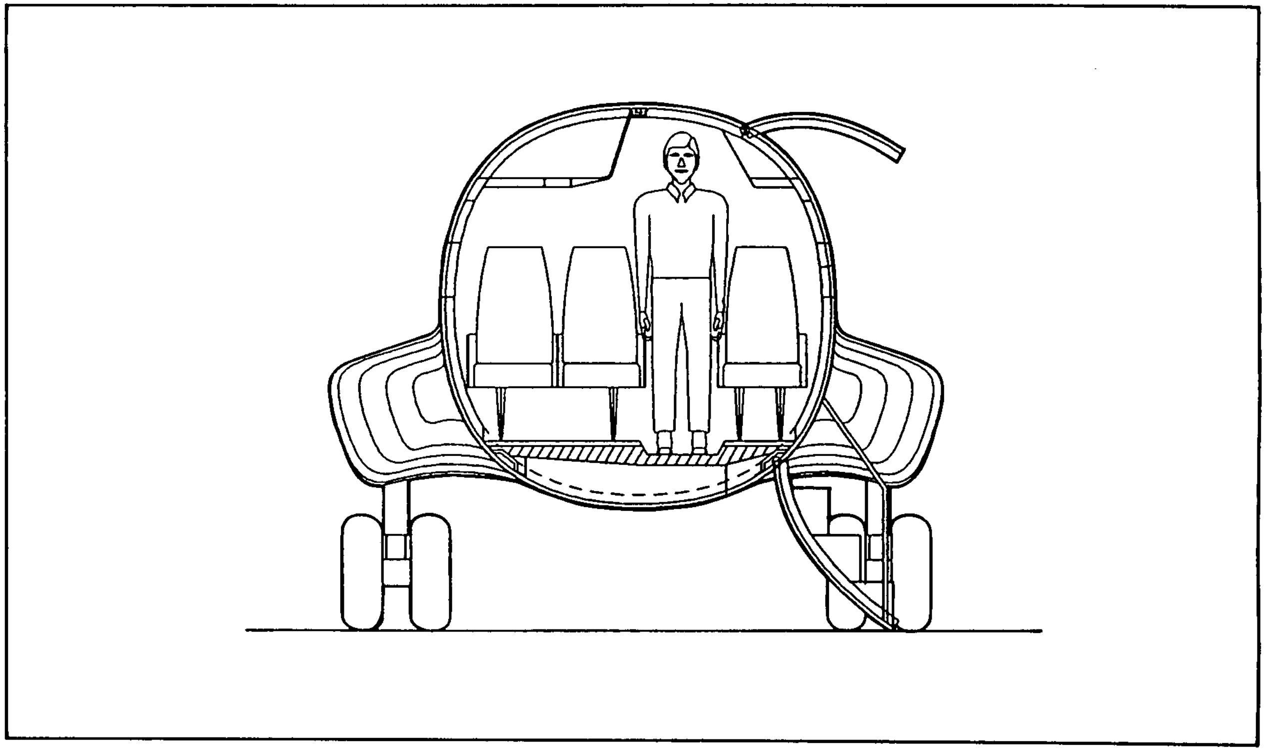
There is no simple answer to the question: which are better, the V-22 derivatives or the all-new designs? Both have their benefits—and their markets.

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.

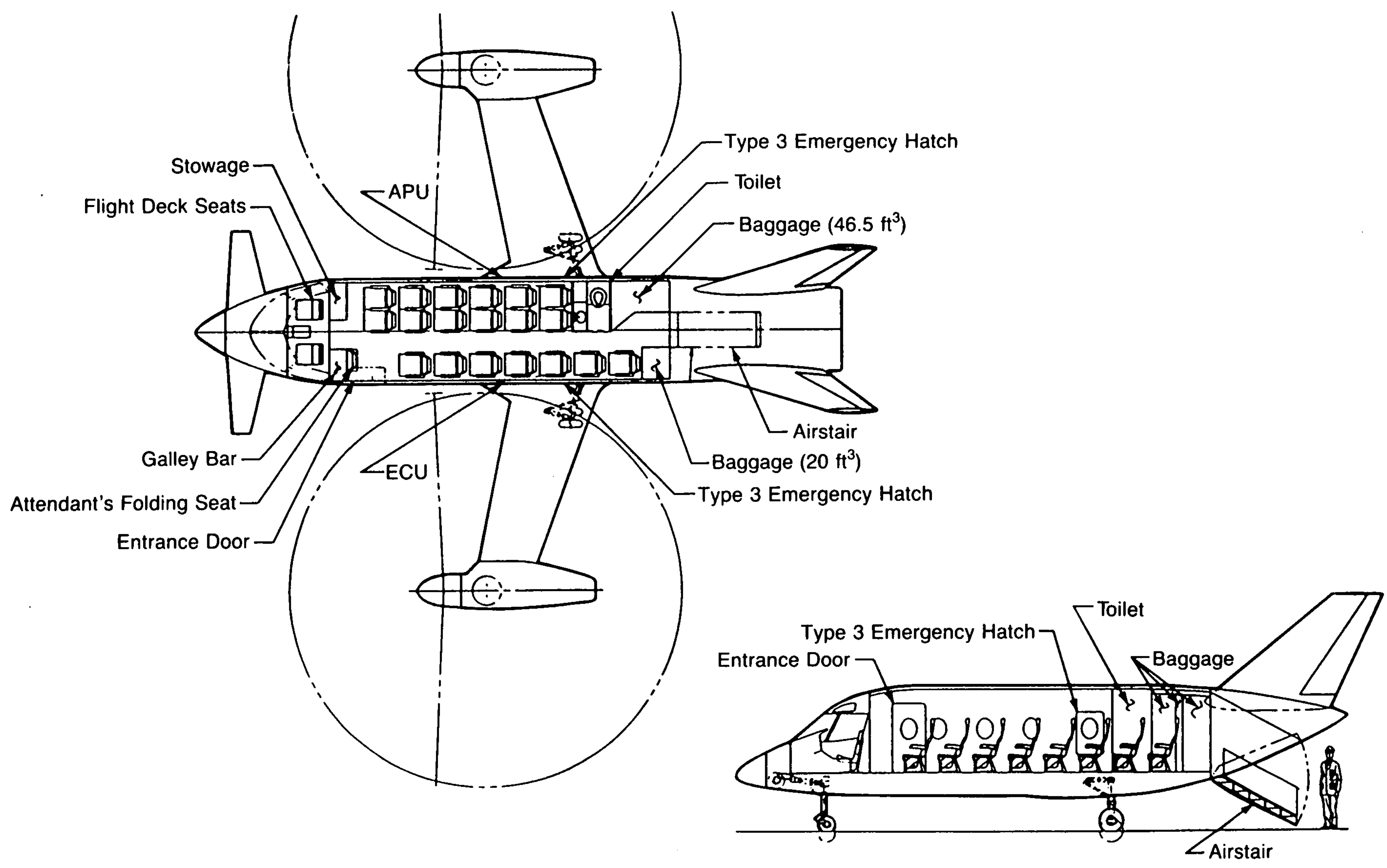
The "all-new" designs also make use of V-22 technological advances; in that sense, they are not "all-new." But the CTR-1900 and CTR-7500 do differ substantially from the CTR-22 series and offer a number of advantages:

- 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.



CTR-22C


Stowage
Flight Deck Seats
APU
Type 3 Emergency Hatch
Toilet
Baggage (46.5 ft³)
Galley Bar
Attendant's Folding Seat
Entrance Door
ECU
Airstair
Baggage (20 ft³)
Type 3 Emergency Hatch
Toilet
Type 3 Emergency Hatch
Entrance Door
Baggage
Airstair

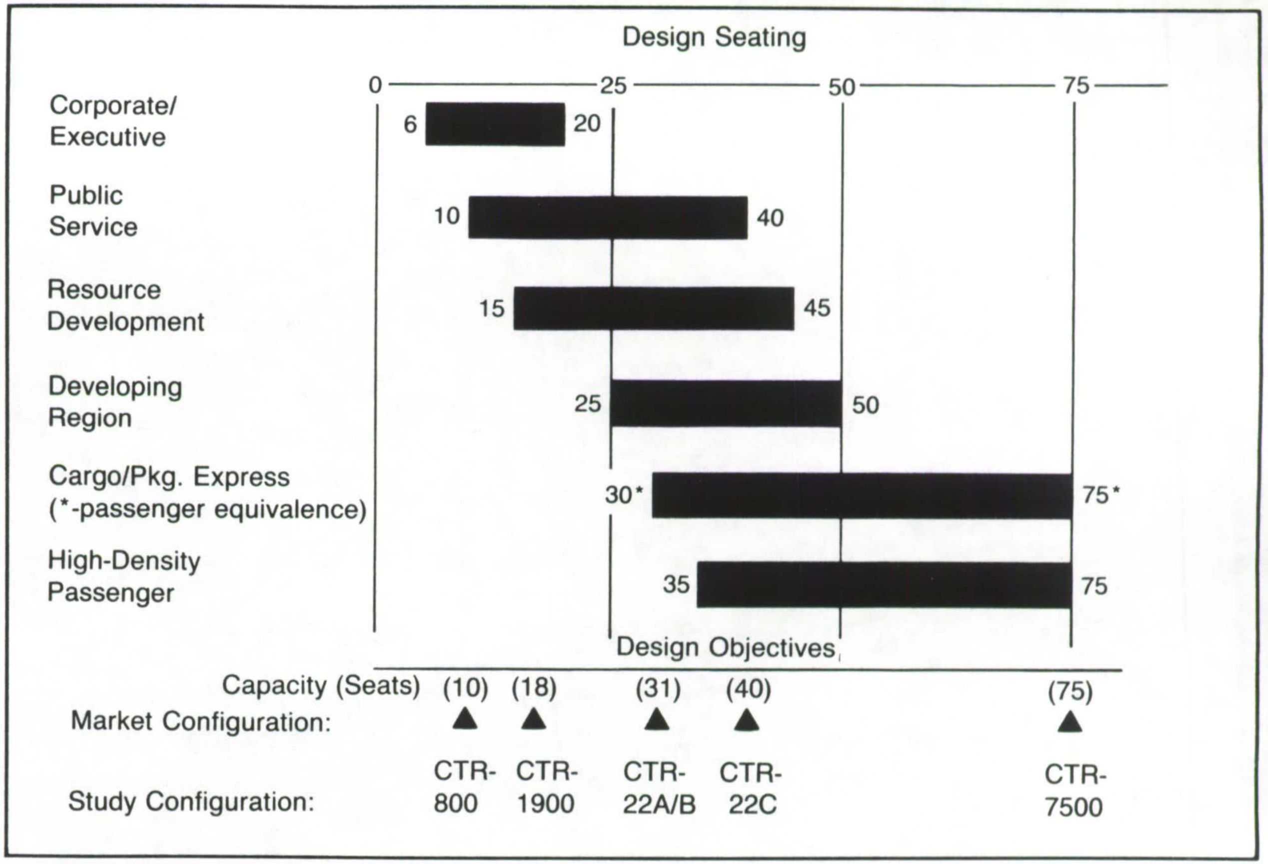
Markets: Overview

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

	Corp/Exec	Government Public Service	Low Density	Resource Develop-ment	Cargo/ Package Express	High Density
Maximum Potential		35	85	110	120	1200
Nominal Market Penetration	• CTR-22B: 50 to 100 • CTR-22C: 100 to 700 • CTR-22D: 200 to 500					

Demand: V-22 Derivatives

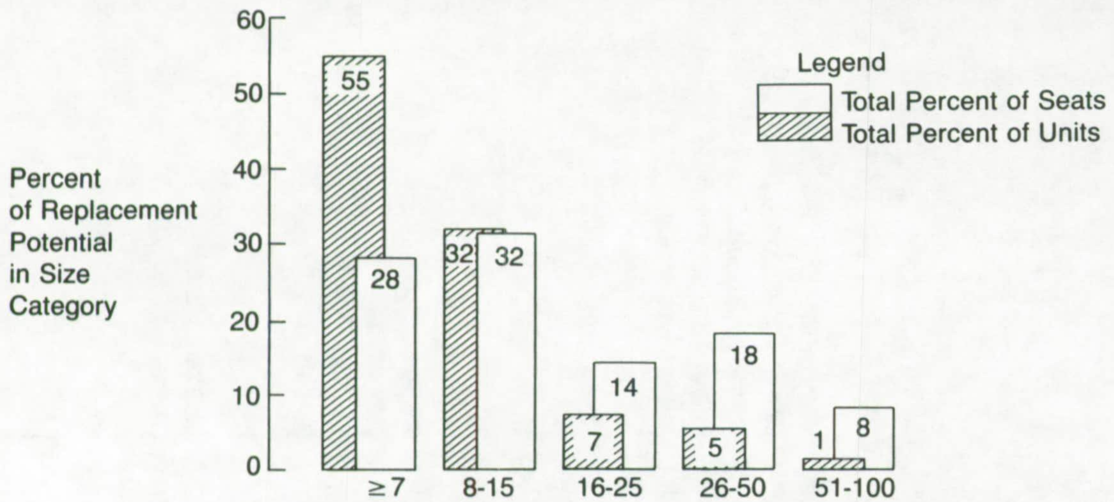
Markets:
Overview (continued)

Total market potential is very large: tiltrotors could perform the mission of more than 16,000 units of existing fixed-wing and helicopter inventory. Bulk of market is in North America (65-75%).

To identify and provide a focus for the study of candidate markets, three perspectives were used:

- Survey of prospective users of tiltrotors.
- Existing inventories of fixed-wing and helicopter aircraft.
- Extensive look at past surveys and studies to place this study in proper historical perspective.

Market design criteria are listed below. A range of sizes is needed. VTOL is preferred to STOL. Cabin pressurization was believed necessary for operational flexibility and passenger comfort (competitive features) and for longer range economy.



Potential Tiltrotor Replacement of Eligible Existing Equipment

Study Size Category (Seats):	Corp/Exec	Gov't Public Service	Low Density	Resource Development	Cargo/ Package Express	High Density	Potential Total Units
6 to 15	475	75	20				570
16 to 25	175	75	50	325			625
26 to 35		35	85	110	80		310
36 to 45			65	85	80	1200	1430
46 to 55			50		120	700	870
56 to 100						400	400

Note: Size Categories Are Mutually Exclusive; Totals Cannot Be Added.

(shaded) Minimal Demand

Demand: "All New" Designs

- 600 N. Mile Range with OEI Hover Takeoff
- 800 N. Mile Range with 750 ft. STOL
- Cabin Pressurization
- Noise - Equal or Less Than Current Aircraft
- Utilization Objectives: Minimum - 2000 hr/yr at 98% Dispatch Reliability
- All Weather Operation
- Wing Stow not Required (V-22 Feature)
- Rotor Blades Designed with Manual Folding
- Ramp Self Sufficiency - Air Stair; APU; Power Back
- FAR Certification 1995

Market Design Criteria

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.

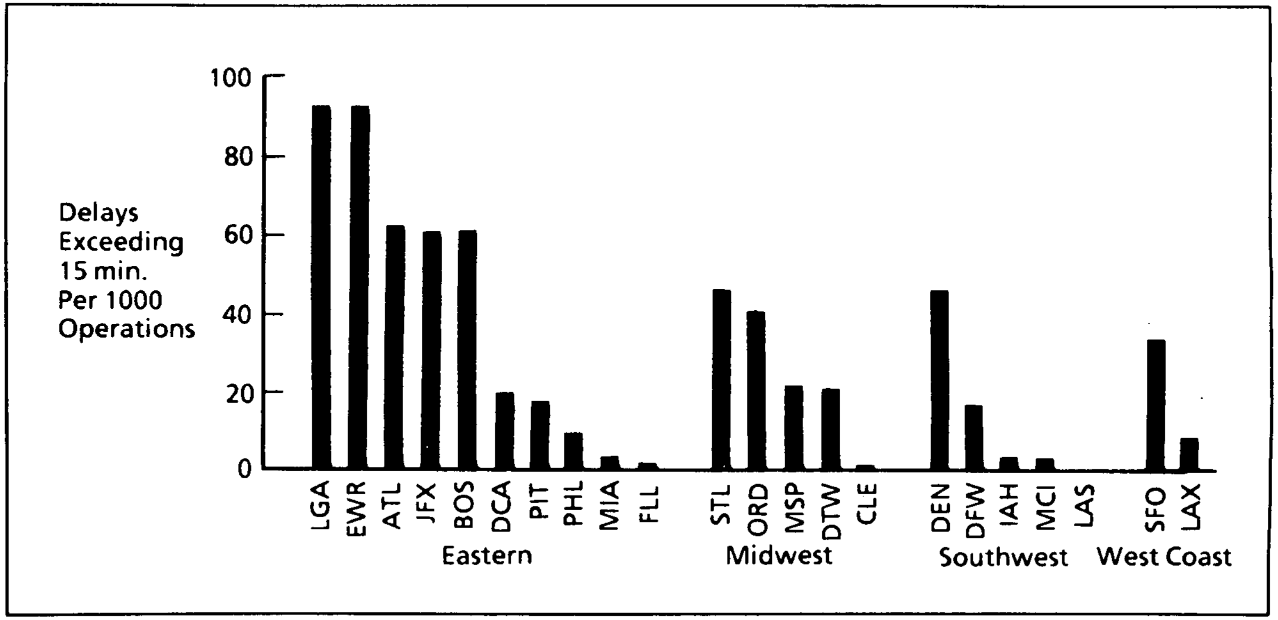
Civil tiltrotors could capture one-third to two-thirds of this market. Key to tiltrotor's success is its VTOL ability, perceived as a necessity at one or both ends of each trip.

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.

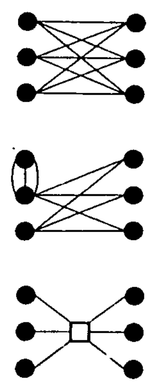
Another factor will be the number and location of vertiports. In the New York, Boston, and surrounding area, for example, 18 vertiports properly located would yield good penetration. Initially, it is expected that existing airfields could support some tiltrotor service; single-purpose vertiports would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

New York Boston Example



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

*Year 2000

Tiltrotor Potential Market Share

20-29 Passengers		40-49 Passengers	
Inventory	Aircraft	Inventory	Aircraft
		18	HS-748
25	DC-3	11	DC-6
		5	CN-235
22	C212	4	F27J

Caribbean Aircraft Inventory

From	To	Passengers/Year	Distance (Miles)
1. St. John	St. Martin	79,475	108
2. St. Martin	St. John	79,475	108
3. Port of Spain	Bridgetown, Barbados	77,143	208
4. Bridgetown, Barbados	Port of Spain	77,143	208
5. Santo Domingo, Dom. Rep.	San Juan, Puerto Rico	64,536	234
6. San Juan, Puerto Rico	Santo Domingo	64,536	234
7. St. Lucia	Bridgetown, Barbados	44,676	120
8. Bridgetown, Barbados	St. Lucia	42,132	120
9. Bridgetown, Barbados	St. Vincent	36,599	120
10. Panama	San Jose, Costa Rica	34,658	350
11. St. Vincent	Bridgetown, Barbados	31,938	120
12. San Jose, Costa Rica	Panama	31,126	350
13. Port Au Prince	Santo Domingo	31,730	170
14. San Salvador, El Salvador	San Jose, Costa Rica	30,939	440
15. San Jose, Costa Rica	San Salvador, El Salvador	29,546	440
16. Santo Domingo, Dom. Rep.	Port Au Prince, Haiti	25,931	170

Carribbean Passenger Routes

Markets: Low-Density Market

The low-density market is difficult to analyze because of the diversity of the market and the lack of specific market data. It is a large market, geographically, consisting of such regions as southeast Asia, Oceania, Alaska, northern Canada, and the Caribbean. The lack of ground infrastructure is one commonality in this market. Opportunities could include tourists, light, high-volume industrial products, and foodstuffs.

There is also a potential market in low-density areas for resource development applications; these are discussed in the resource development market summary on the next page.

The Caribbean archipelago was examined as a low-density market case study. Many political entities are present in the region, transportation between population centers is relatively undeveloped, and economies are generally poor. For these reasons, tiltrotor service could increase the quality of life, but government support would be needed.

Alaska merits special mention as it represents a somewhat atypical low-density market. Environmental conditions are extreme and the population is very small. Smaller settlements are widely spaced and air travel is well-established as the only feasible method of year-round transportation. The tiltrotor could replace many of the fixed wing STOL aircraft now in service and reduce the need for snow removal or regrading of frost upheavals. The tiltrotor has particular advantages in serving new destinations, and it could eliminate the need for extensive fleets of float/ski planes.

In all of the low-density markets examined, economic development is essential to the success of tiltrotors. Until light industry (or resource development) increases—and with it the demand for new air transport—the potential for tiltrotor in this market will remain limited.

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.

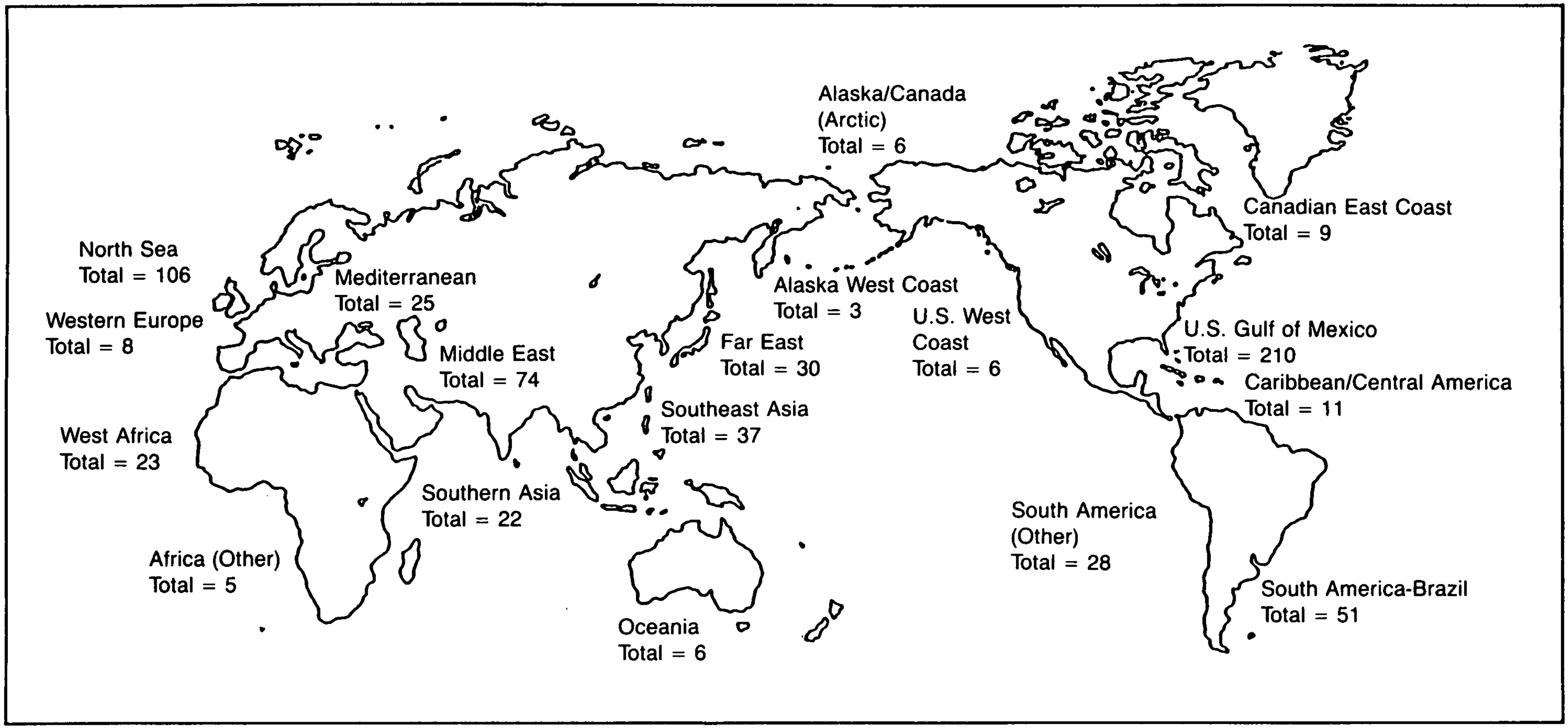
The numbers also do not reflect any other resource development markets besides oil and gas. More market analysis work is required to assess the extent of this additional demand.

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.

Region	Total Number of Rigs	Percent of Base Case	Units Projected		
			CTR-1900	CTR-22A/B	CTR-22C
North Sea	106	100%	51	17	13
Gulf of Mexico	210	198%	101	34	26
Middle East	74	70%	36	12	10
South America/Brazil	51	48%	25	9	7
Southeast Asia	37	35%	18	6	5
Far East	30	28%	15	5	4
Other South America	28	26%	14	5	4
Mediterranean	25	24%	13	4	4
West Africa	23	22%	12	4	3
Southern Asia	22	21%	11	4	3
Caribbean/Central America	11	10%	6	2	2
Canadian East Coast	9	8%	4	2	2
Western Europe	8	7.5%	4	2	1
Alaska/Canada (Artic)	6	6%	3	1	-
Oceania	6	6%	3	1	-
United States West Coast	6	6%	3	1	-
Other Africa	5	5%	3	1	-
Alaska West Coast	3	3%	2	-	-
Total			324	110	86

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

Tiltrotor Potential



World's Oil Platforms

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 supplant 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.

Disaster Relief

An additional public role is disaster relief. Tiltrotors for this role would be drawn from available fleets in an area (police, fire, drug enforcement, even military).

For moving large numbers of people from the scene of man-created or natural disasters, the tiltrotor's speed and VTOL capability make it ideal. The tiltrotor could also move supplies and machines into stricken areas rapidly.

Market Size—Public Service

Predicting market penetration is difficult. A conservative estimate was made that between 35 and 75 tiltrotors would satisfy demand by the year 2000, depending on the size of configurations available. There are more than 2,500 helicopters now in public service; about 1,100 of those are estimated to be eligible for replacement by tiltrotors (i.e., are large single-engine or twin-turbine models).

Markets: Corporate/Executive Market

The corporate/executive transport market is very large (see table to right). Over 11,000 aircraft are now in use in this market, about evenly split between fixed-wing turboprops and helicopters.

Several important points about this market need to be stressed. Corporations are very cost-conscious and aware of the importance of making effective use of business aircraft. They also understand that corporations making effective use of business aircraft are more profitable and have higher productivity per employee than those who do not, as reported by **Business Flying** magazine in 1985.

Executive security is an increasingly important factor, as well. Cabin pressurization is essential. Speed, efficiency of operation, low maintenance, and mission flexibility are also important attributes of business aircraft.

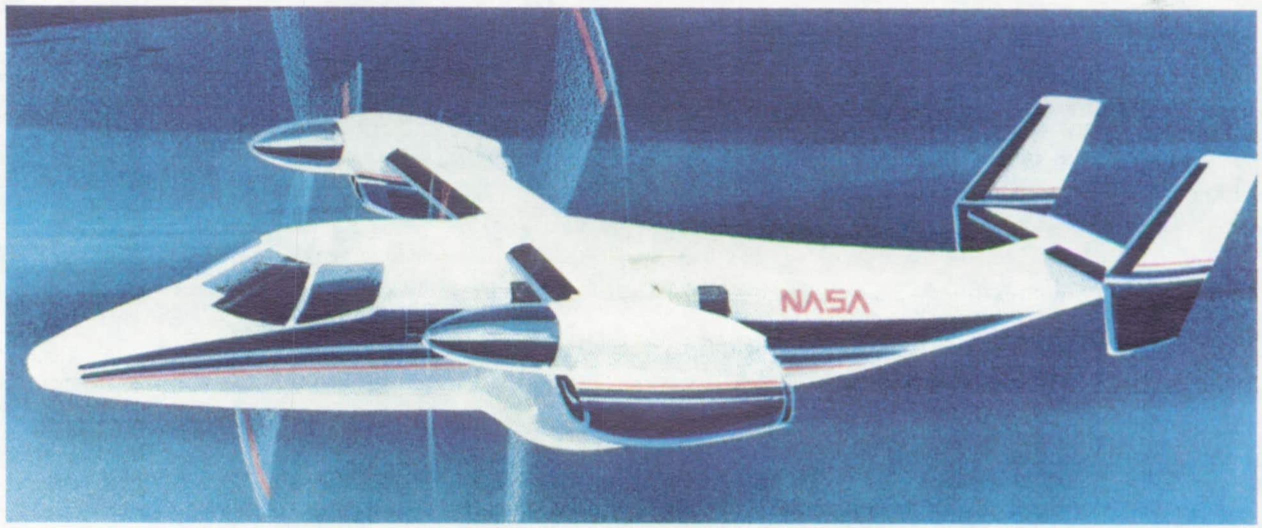
The smaller versions of the civil tiltrotor offer benefits on all counts. They are fast, efficient, and flexible. Their VTOL capability offers substantial savings in time at both ends of the flying journey, and their high speed cruise allows them to replace airplanes as well as helicopters.

Executive transport remains the prime mission of business aircraft, but other uses are becoming more important; transport of critical skills and shipping of high-value equipment and information contributes to overall efficient utilization of aircraft.

The CTR-800, the pressurized 8-passenger, XV-15-sized tiltrotor, is particularly attractive in this market. By the year 2000, the CTR-800's market share could be 450 to 500 units. The larger CTR-1900 (19 passengers) would account for a market share of about 150 to 200 units, if it were available instead of the CTR-800.

	Helicopters	Turboprops
Africa	120	100
Asia	350	50
Central America	70	90
Europe	840	300
North America	3,740	5,020
Oceania	80	50
South America	130	300
Total:	5,330	5,910

Incumbent Market

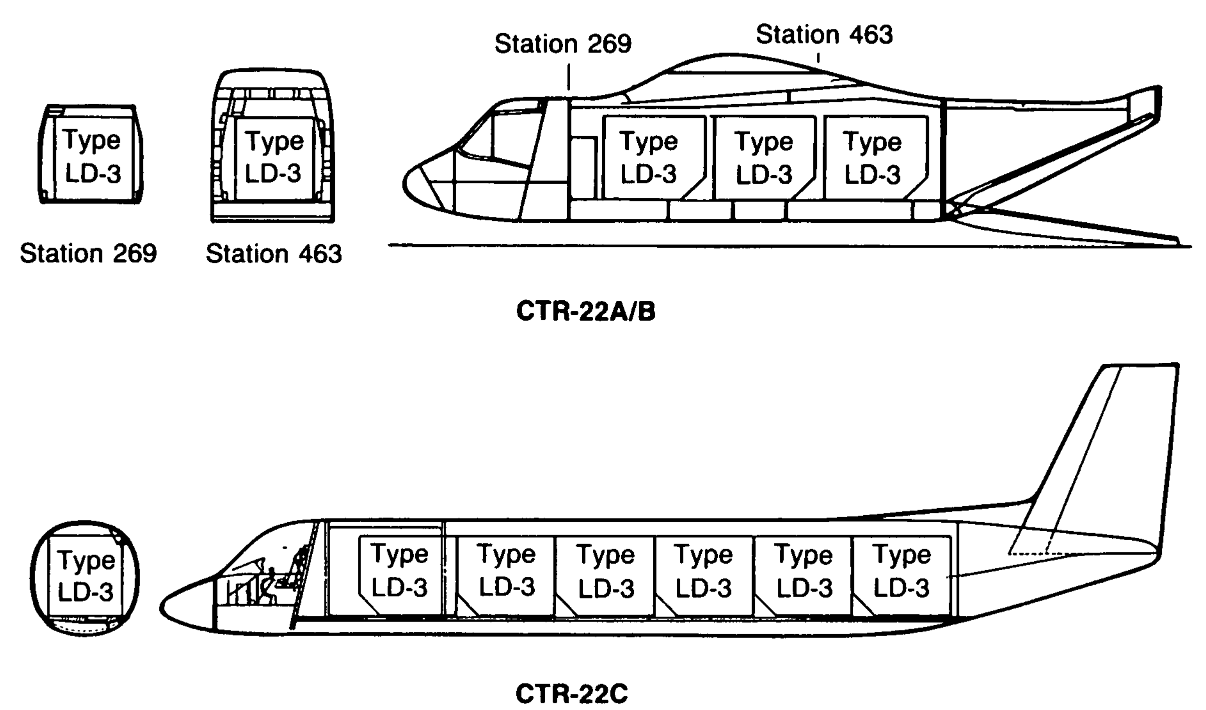


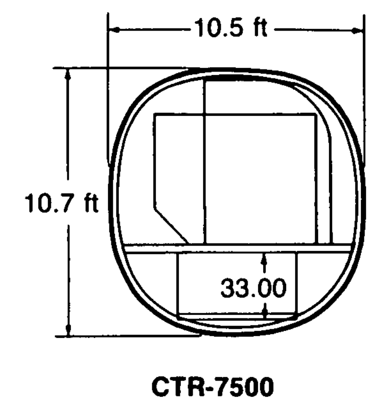
Markets: Cargo/Package Express

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.

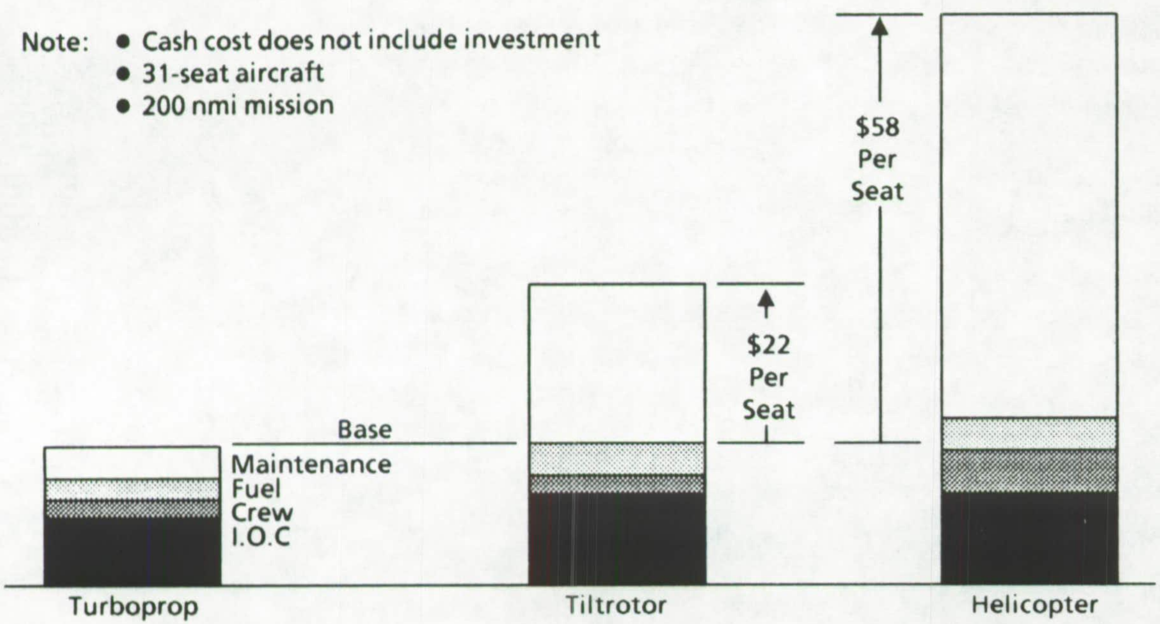
A complete market study is required to obtain good figures for tiltrotor market penetration. Preliminary analysis shows some acceptance of tiltrotor, however, and an estimate was prepared based on the list of cities below and the number of tiltrotors required to serve each city. This yielded a market 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.





Cargo Configurations

North America	Latin America	Europe
Atlanta	Buenos Aires	Amsterdam/Benelux
Boston	Mexico City	Cologne/Frankfurt
Dallas/Ft. Worth	Montevideo	London
Denver/Colorado Springs	Rio de Janiero	Manchester/Northern U.K.
Chicago/Milwaukee	Sao Paulo	Milan
Houston	**Asia**	Paris
New York/Long Island	Tokyo	
San Francisco Bay Area	Fukuoka	
Washington D.C./Baltimore	Nagoya	
	Osaka-Kobe	



Aircraft Portion of Trip (Block Time):

Turboprop	Tiltrotor	Helicopter
.97 hr.	.92 hr.	1.62 hr.

Total Trip Time (Portal-to-Portal):

Turboprop	Tiltrotor	Helicopter
4.0 hr.	2.0 hr.	2.7 hr.

Cash Operating Cost Comparison

Economics: Overview

A number of important conclusions were reached during analysis of the economics of the civil tiltrotor. They are listed below and discussed on the following three pages.

The civil tiltrotor halves the difference in cash operating costs (non-investment costs) between fixed-wing and helicopter aircraft. This is shown in the figure to the left.

Compared to multi-engine helicopters, the economics of the tiltrotor are clearly superior.

Considering that the true cost and time of a trip is from portal-to-portal, the tiltrotor can be competitive with fixed-wing conventional aircraft. Stated another way, using only a modest dollar value for time and convenience, the tiltrotor provides better service to passengers at competitive fares.

More work is needed in technology and design—as well as in more finite market analysis—to reduce operating costs and cost to build and make the tiltrotor even more economically viable.

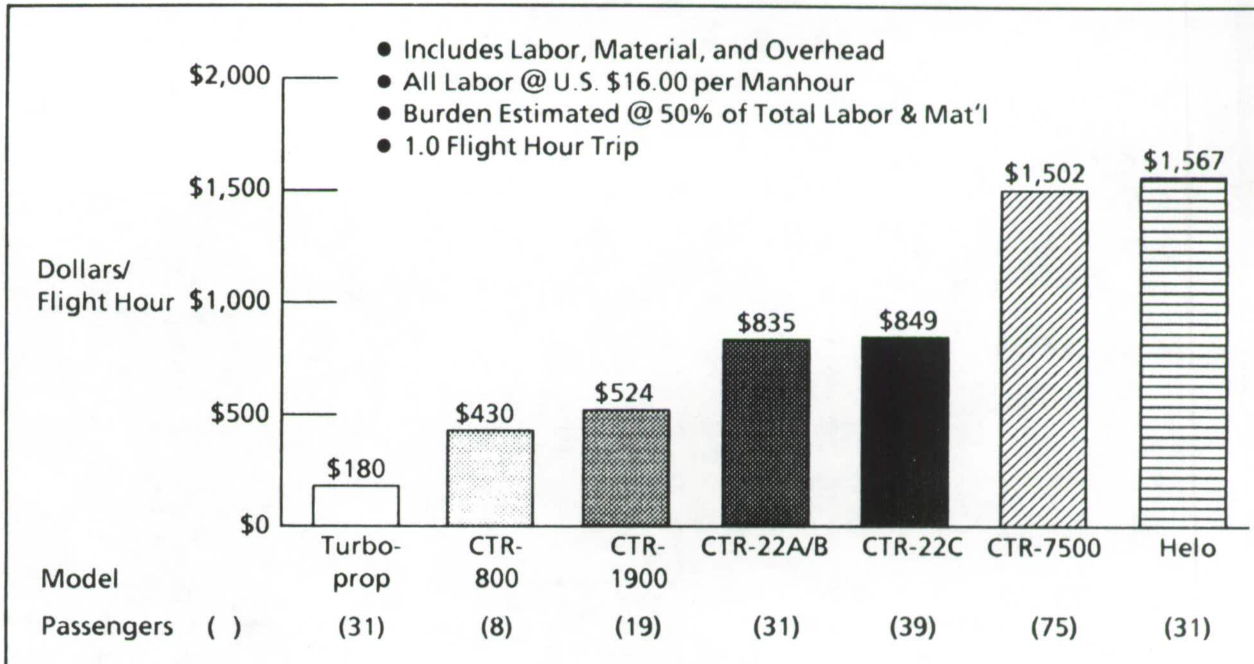
Economics: Operating and Maintenance Costs

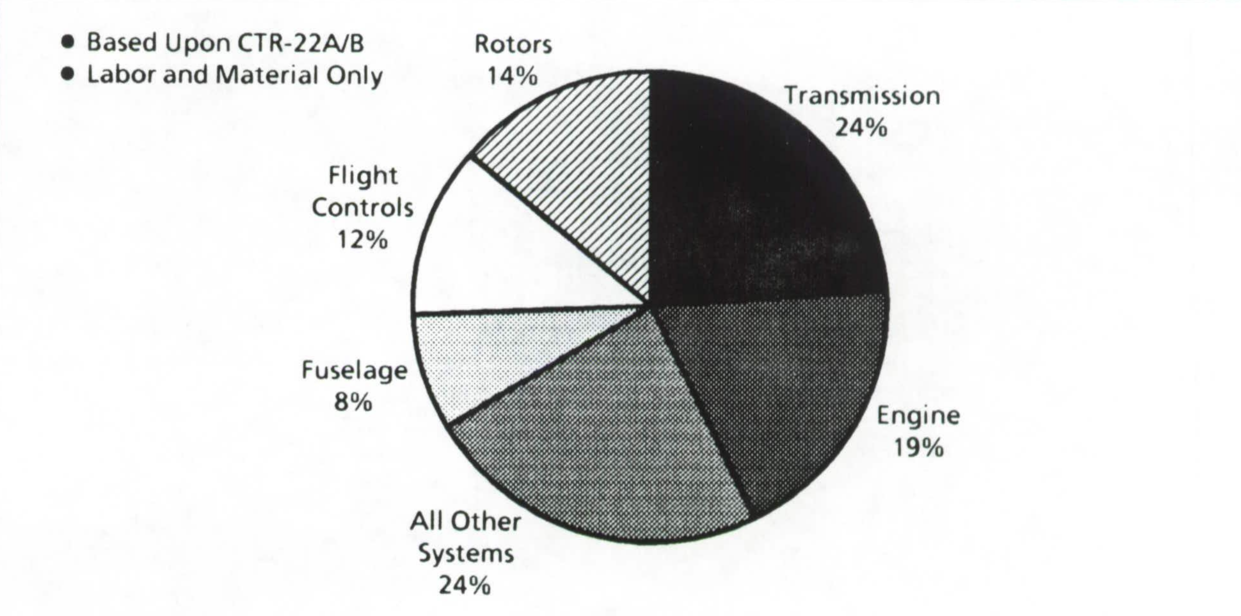
The graphs opposite show an important reason for the tiltrotor's favorable operating costs, as compared to the helicopter: lower costs of maintenance. They also show a typical breakdown of maintenance costs, indicating that over half of the maintenance is in the propulsion system.

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.

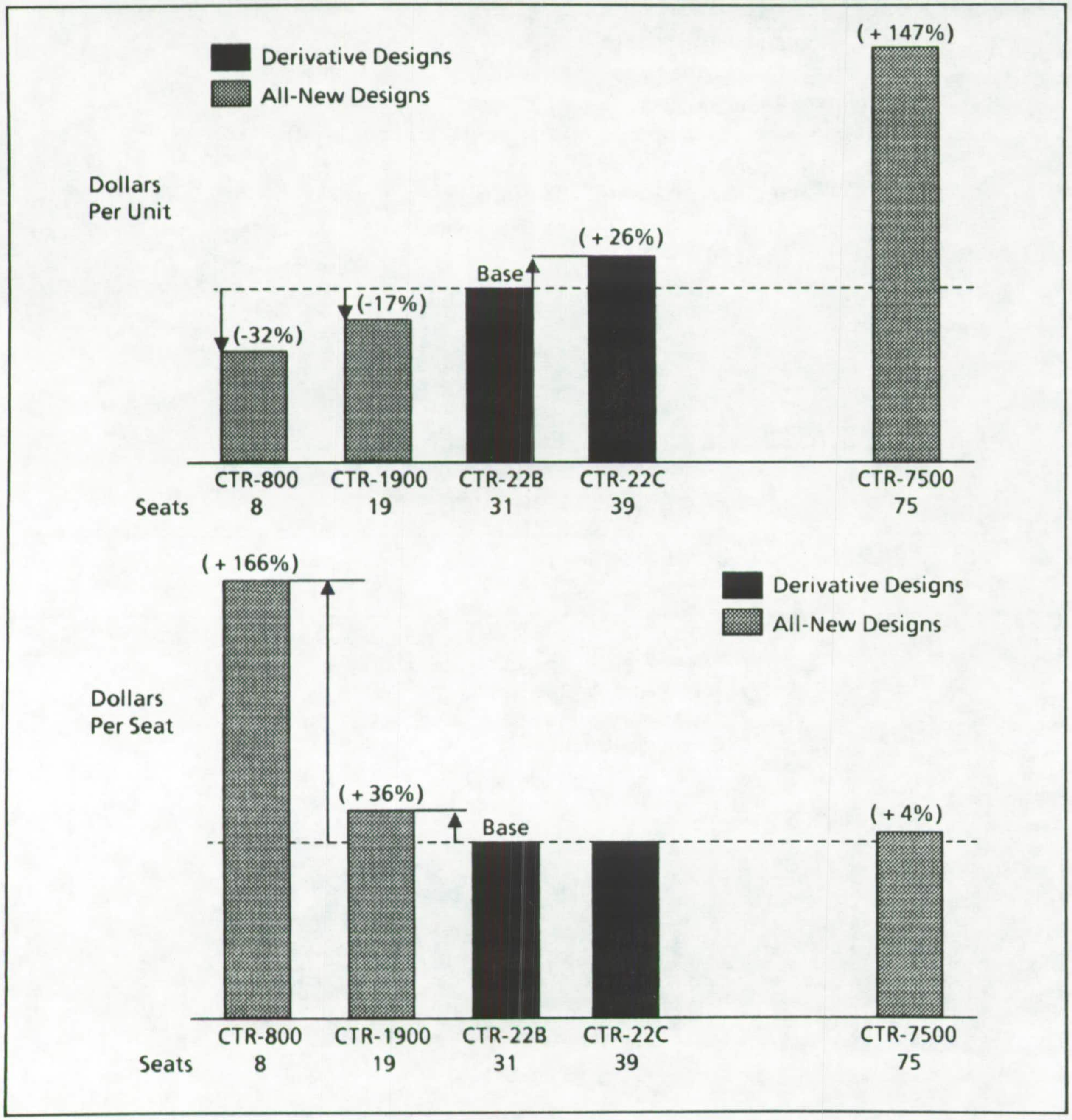
It must be noted, however, that operating costs tell only part of the story. Revenues from operations are the offsetting factor, and here the tiltrotor has a potential advantage over fixed-wing aircraft: its greater convenience and time savings can result in greater revenues per passenger.

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).





Maintenance Costs



Cost-to-Build Comparisons (Average Cost per Unit Over 300 Units)

Economics: Cost to Build

Shown to the left are several important conclusions. The relative cost to build each of the five principal tiltrotor configurations, including nonrecurring costs, are indicated by the upper bar graph. This analysis is based on V-22 estimates and, in the case of V-22 derivatives, reflects benefits from the V-22 learning curve in the 1995 time frame. It should also be noted that the costs to build shown are exclusive of manufacturer's profit, an element that must be considered in completing any analysis of economic feasibility.

The cost to build of each major configuration—on a per-seat basis—is shown in the lower bar chart.

This study and other general cost studies have shown that a tiltrotor should be expected to cost up to 50% more than a turboprop of equal capacity, where each is designed to the same commercial criteria, utilizes common material and construction standards, and reflects equally mature technology. More analysis is needed, however, and it is considered essential to include detailed cost-to-build studies in any follow-on tiltrotor work.

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.

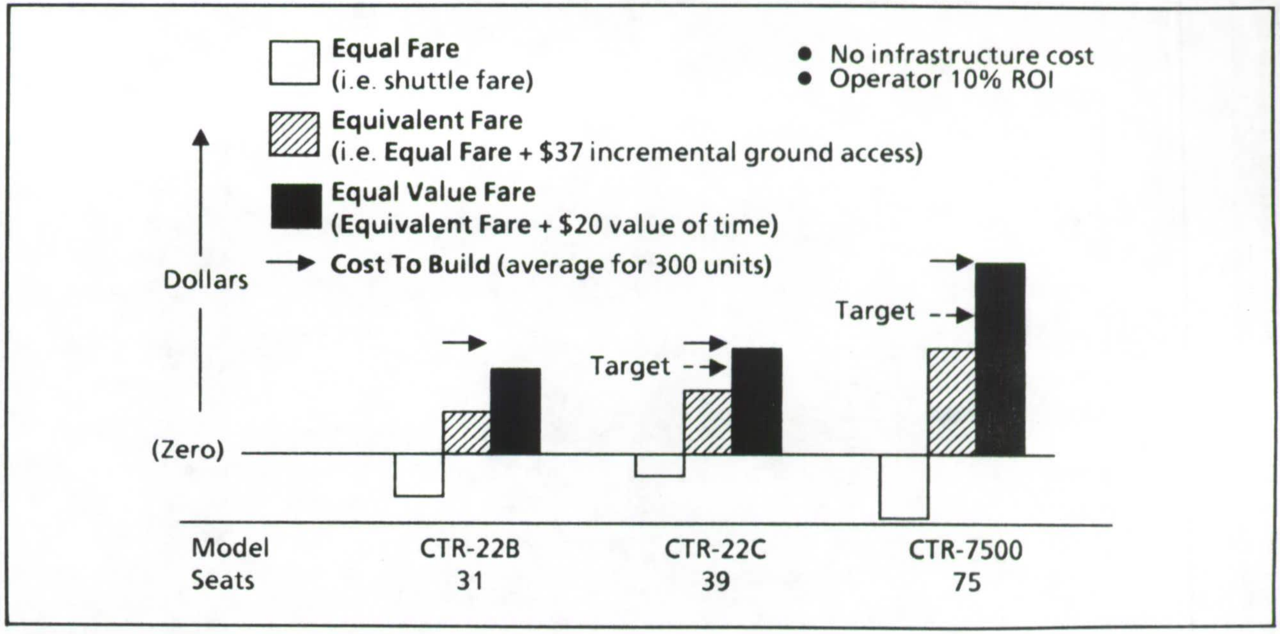
For the high-density market, using New York-Boston as an example where tiltrotor would compete with fixed-wing fares, the tiltrotor must receive credit for saved ground access costs ($37 average), plus a credit of $20 for the value of commuter time saved, if it is to be competitive to operators who want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

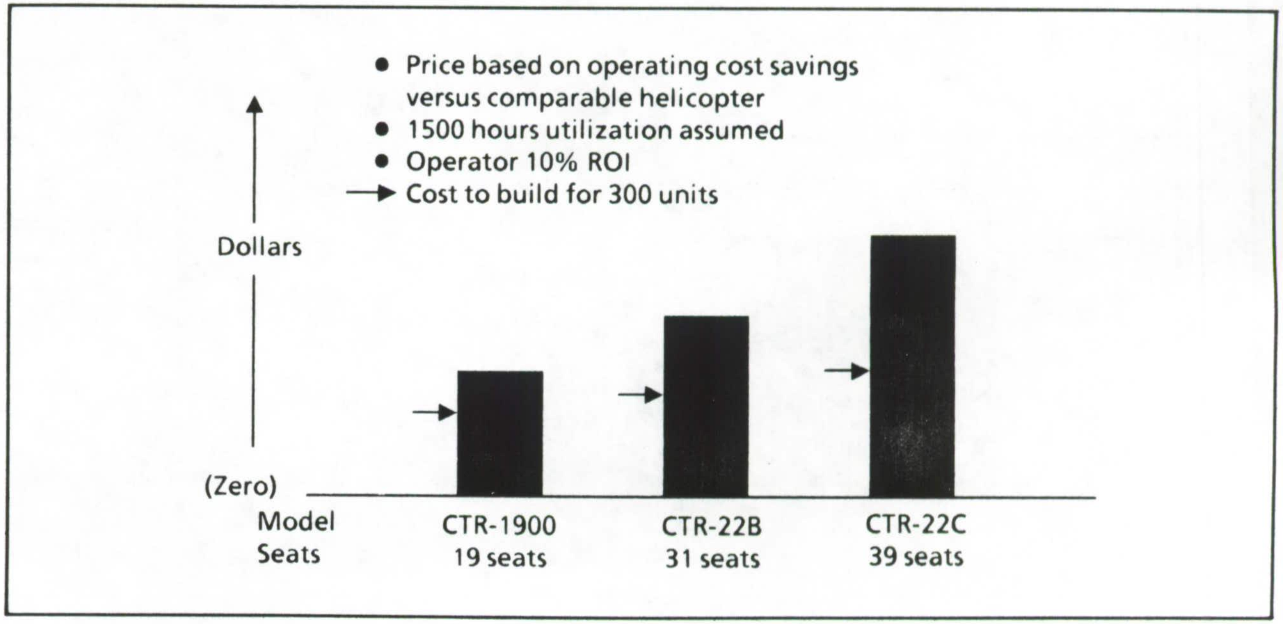
The lower bar chart shows the offshore support scenario, where tiltrotors would compete with helicopters. Tiltrotor values far exceed their cost to build in this market, even when fares for helicopters and tiltrotors are equal.

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

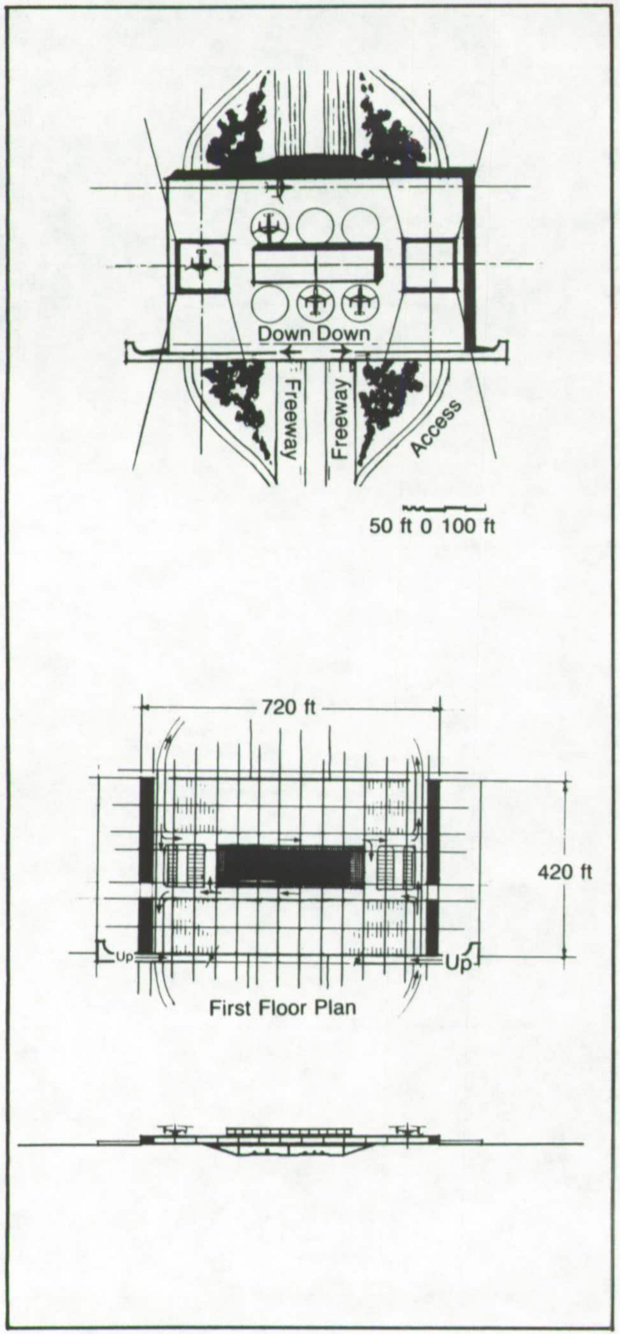
- Its unique advantages are exploited by a fully developed infrastructure (vertiports, surface transport interface, air traffic control).
- Tiltrotors large enough to allow economies of scale—in operation and in cost to build—are developed.
- Efforts are continued to provide a vehicle responsive to civil requirements.
- Joint government/industry efforts to develop a civil tiltrotor transportation system are continued.



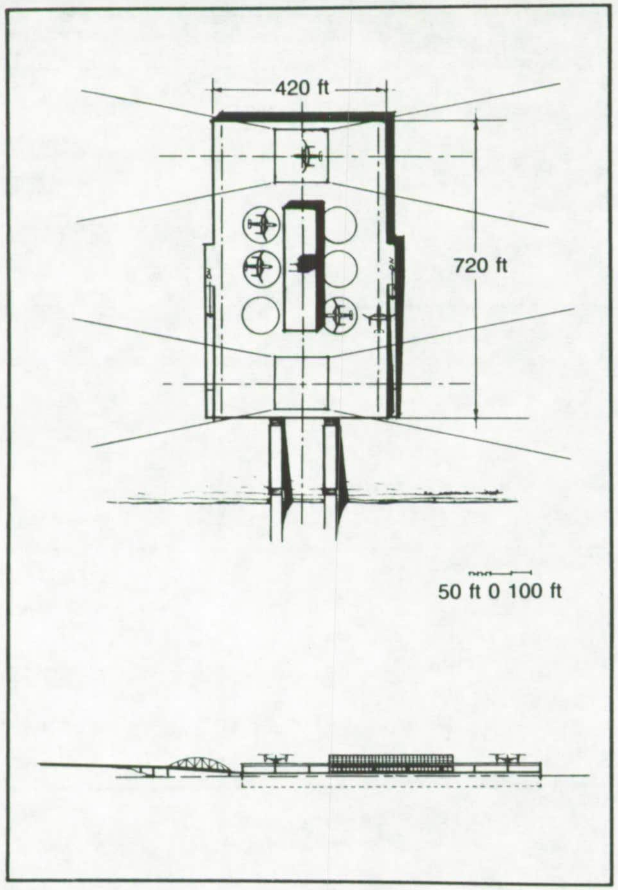
Market-Based Price (New York/Boston Scenario)



Market-Based Price (Offshore Oil Market)



Vertiport Over Freeway



Floating Vertiport

Other Issues: Facilities

To predict vertiport facilities needed to support the high-density commuter market, the New York market was examined as typical. For that market, using a 39-passenger tiltrotor as an example vehicle, 18 vertiports would be needed within a 300 nmi radius of New York City, including 6 within the NYC metro area. Each NYC vertiport would serve, on the average, 3000 passengers per day each way.

Each vertiport would be custom designed for its unique location and traffic.

Several possible designs were postulated and two are shown to the left. The view at far left shows a possible vertiport above a freeway. Such a vertiport would take advantage of available airspace, which is generally free of obstructions, and would make use of property already used for public purposes.

Another possible design shown is the floating vertiport. Waterfront property, while usually expensive, has a large advantage in having unobstructed airspace available in at least one direction.

Vertiport construction costs will vary widely, depending on the location (urban or suburban), size (5 acres for urban and 25 or more for suburban), and the costs of land. Excluding site costs, vertiport construction cost estimates ranged from $11 million for a suburban location to $80 million for a floating design. It is noted that a regular airport is reported to cost $4—$6 billion (**Aviation Week;** 5/4/87).

It is expected that initial tiltrotor service will be partially provided from existing airport facilities. As full service is established, it is expected that specialized vertiports—beginning in metropolitan urban areas—will be required for achieving the maximum tiltrotor benefits in reduced transport time and reduced air and ground congestion.

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, flapperon) 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 display systems, these offer response and stability for optimum handling.

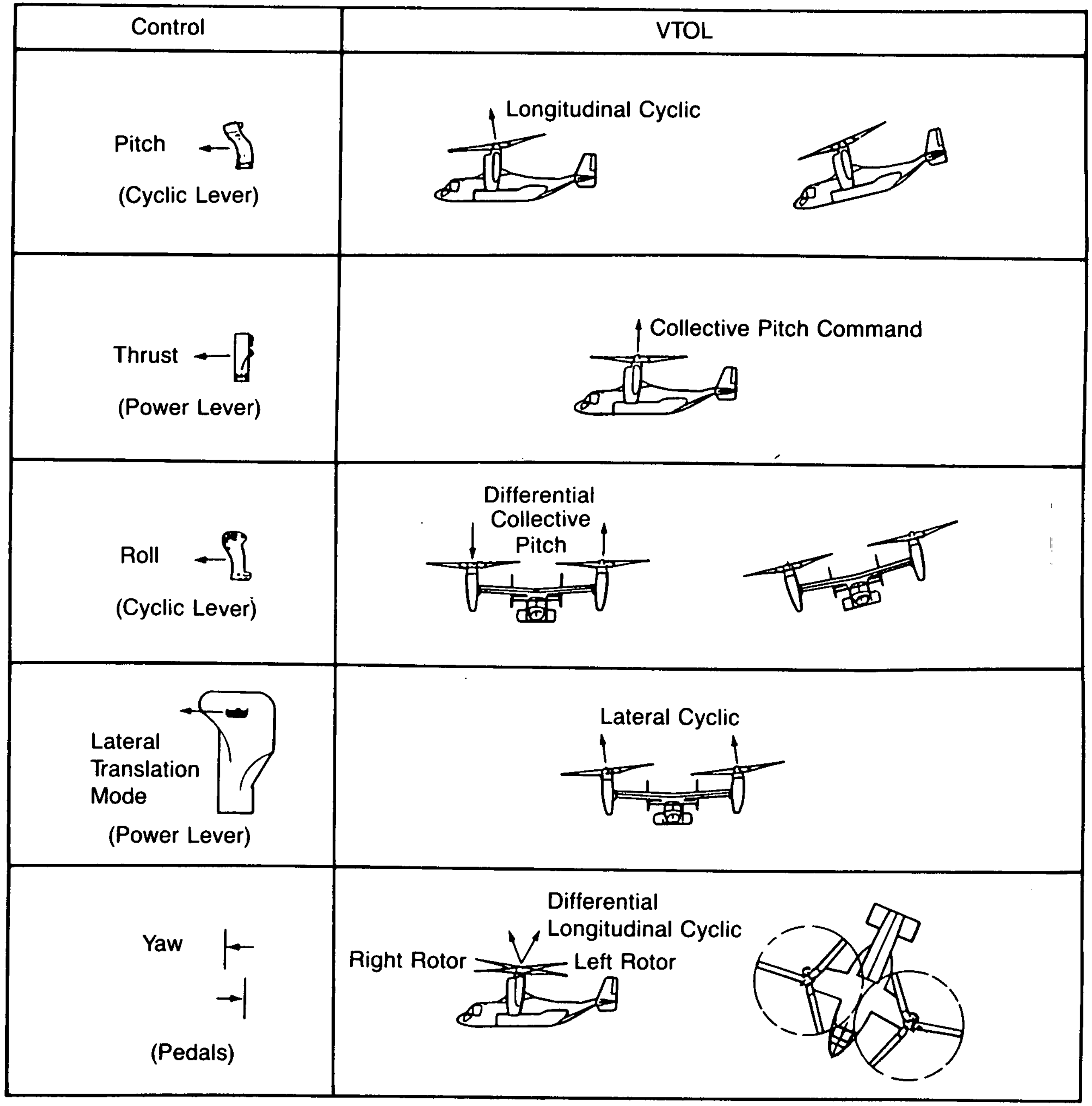
Nacelle rotation accomplishes transition from hover to wingborne lift. The rotor/propulsion system tilts over a range of 97 degrees, and the nacelle angle is synchronized with speed, as shown in the conversion corridor chart. A conversion protection system prevents the aircraft from inadvertent excursions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

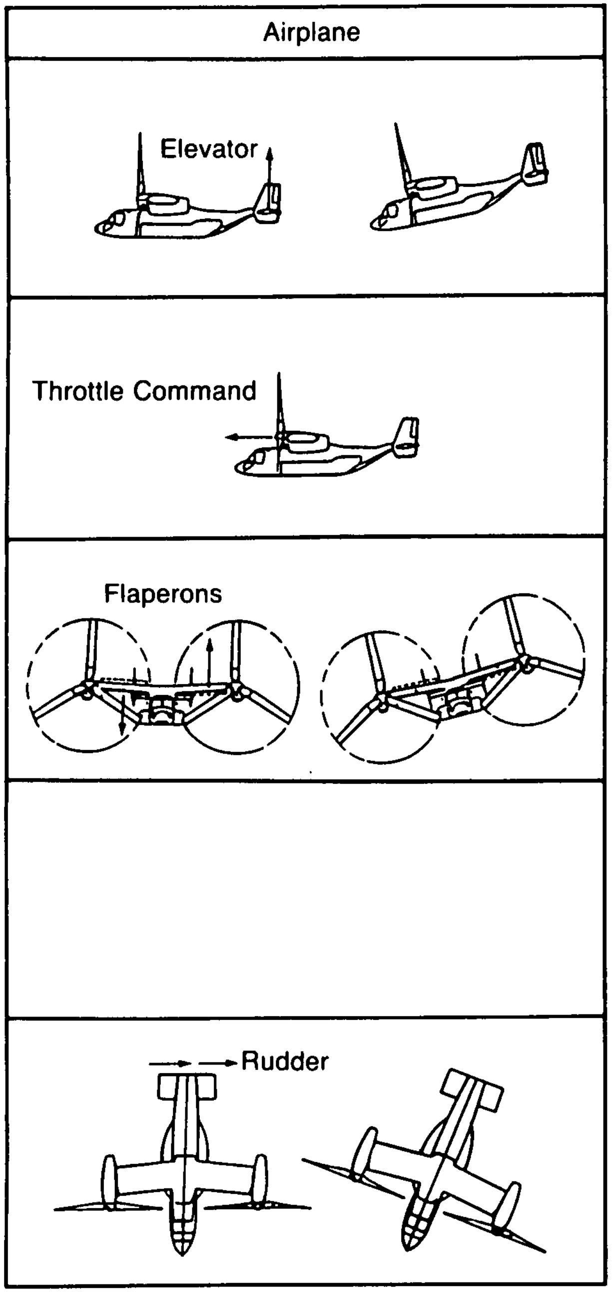
Other Issues: Certification

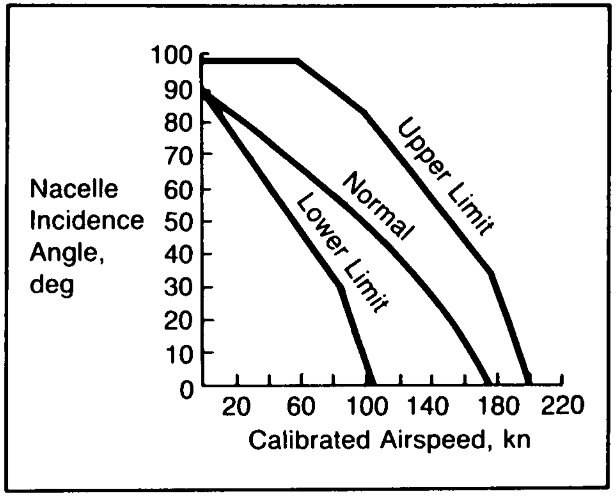
Tiltrotor certification is the subject of ongoing dialogue with FAA. FAA's draft "Interim Airworthiness Criteria for Powered Lift Transport Aircraft" was circulated for comment during this study; an FAA/industry review was held in 1987. Study groups will be formed to discuss specific certification/operational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

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

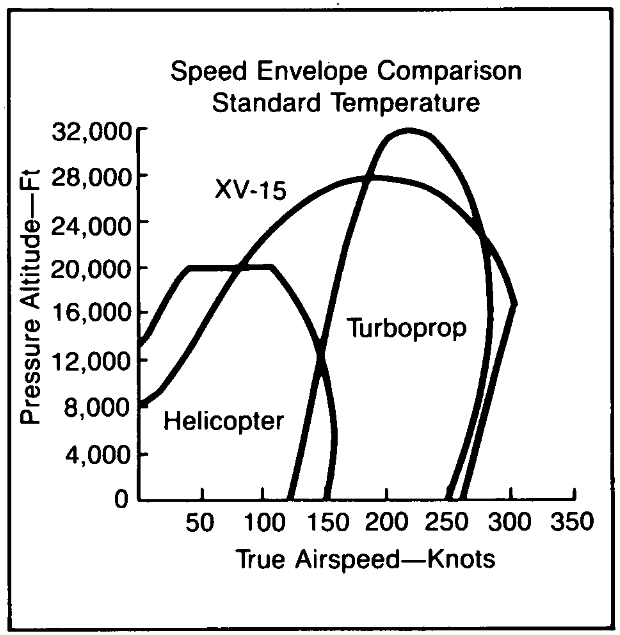


Tiltrotor Controls





Conversion Corridor



Flight Envelope

- Composite manufacturing quality control and field inspection
- Fly-by-wire and multiplex bus controls

Other Issues: Technical Issues

Pressurized Composite Fuselage. Pressurizing a composite fuselage should be structurally no more difficult than pressurizing a metal fuselage. However, questions arise concerning the material failure modes, including tear resistance and sudden decompression characteristics.

Aerodynamic Improvement. Interference drag at the wing/fuselage and wing/nacelle joints must be improved to allow high cruise efficiency. Likewise, the basic wing thickness ratio puts a limit on cruise speed and efficiency, and should be further studied and refined for optimum performance.

High Performance Configurations. New configurations such as canard designs appear to offer substantial performance gains. These need to be quantified in terms of performance, development costs, and operational advantages. Similarly, higher cruise speeds are readily achievable for the tiltrotor, but need further study to evaluate the costs and operational advantages.

Emergency Power Ratings. A 30 second emergency power rating was assumed for this study. Engine manufacturers need to trade off temperature, fatigue damage, and engine life associated with such a rating. Technical studies must determine development costs and impact on the engines' cruise performance, if any.

Technical studies and simulations are also needed to evaluate the emergency landing and takeoff performance associated with single engine performance under the assumed emergency rating.

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.

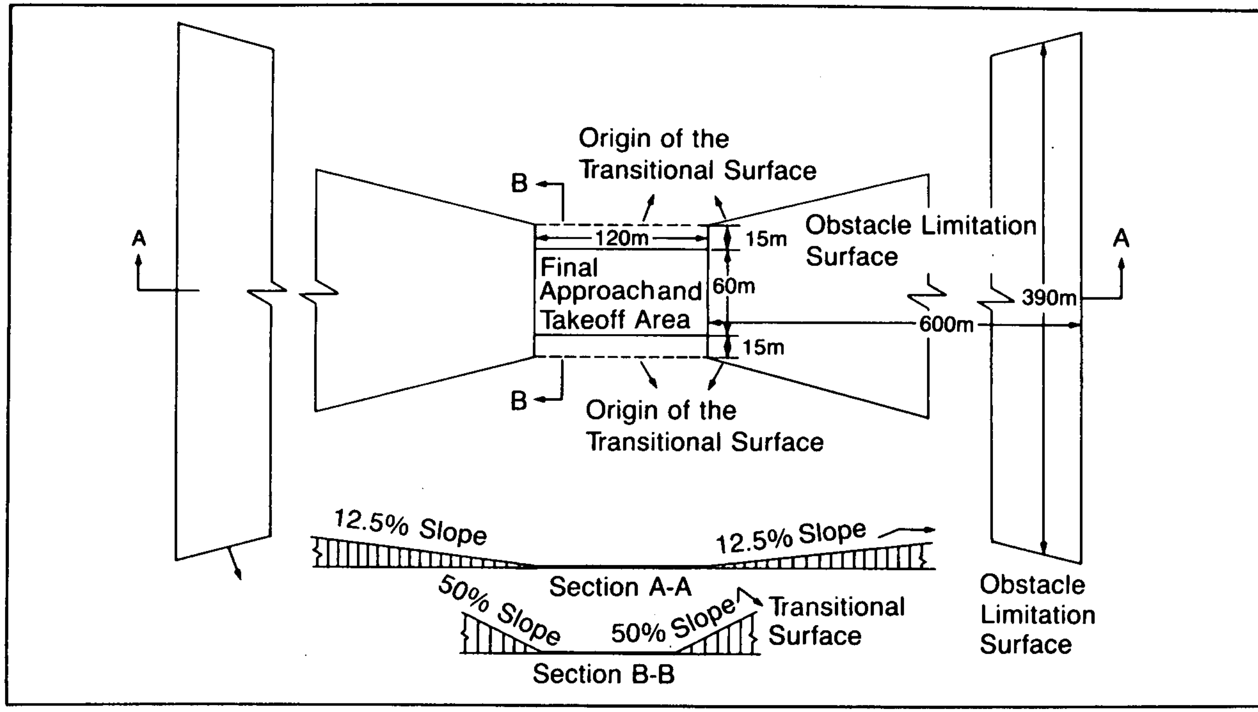
Heliports/Vertiports. New terminal instrument procedures (TERPS) are needed to support IFR operations at vertiports and VTOL instrument flight rule (IFR) operations at current conventional airports and heliports. Particularly, the present obstruction surfaces shown at right need to be modified to take 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.

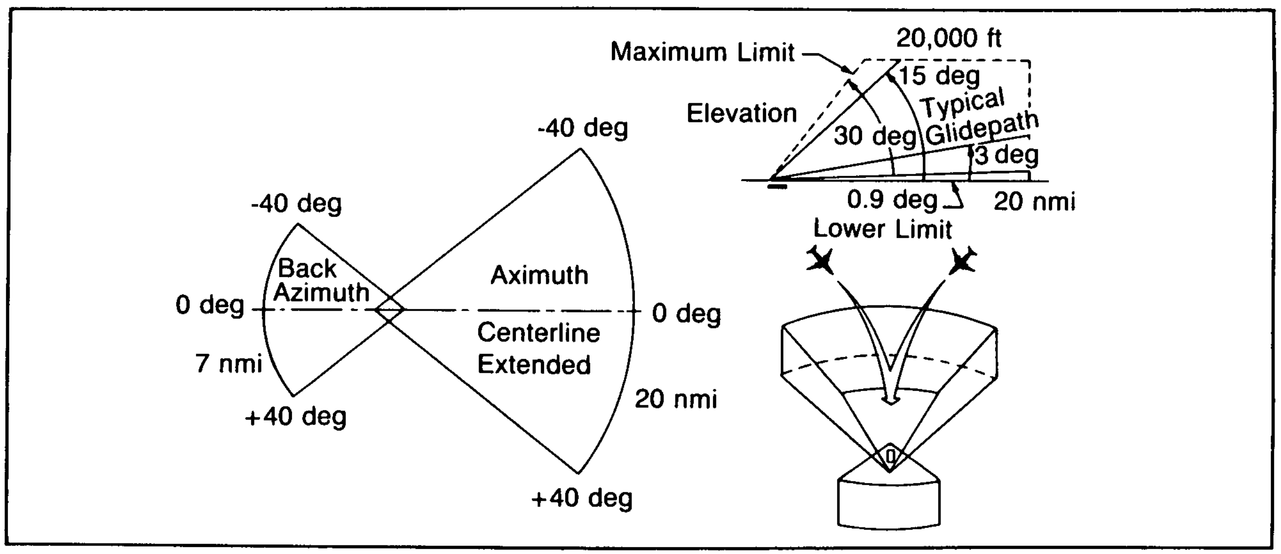
Cockpit displays. Lower approach and landing minimums can be supported with improved displays that show relevant terrain and obstacles.

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.



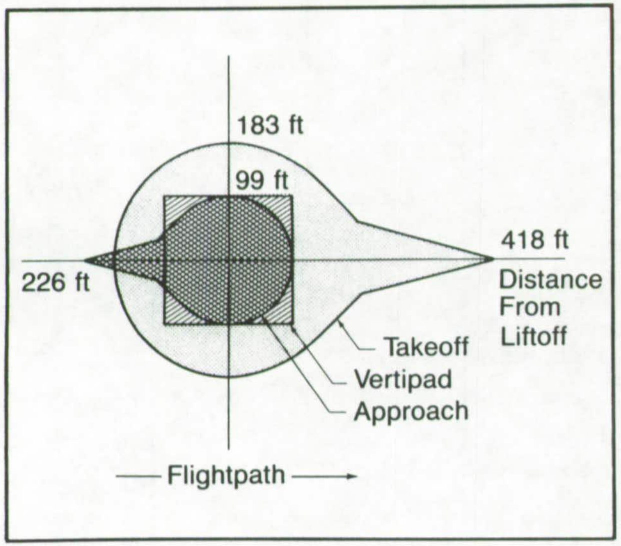
Heliport Obstacle Limitation Surfaces



MLS Spatial Coverage Capability

	Location	Rule	Tiltrotor Estimate	BV-234 Actual	DHC-8-102 Actual
FAR 36 Stage 3 (EPNdB) (Fixed Wing)	Takeoff Sideline Approach	89.0 94.0 98.0	60.0 74.0 77.0	– – –	80.8 86.3 94.8
FNPRM 14CFR (EPNdB) (Rotary Wing)	Takeoff Sideline Approach	101.6 102.6 103.6	78.0 84.0 77.0	96.2 97.2 102.1	– – –

Community Noise Levels



Noise Profile (80 dBA Contours)

Other Issues: Ride Comfort and Vibration

Tiltrotors have inherently lower vibration levels than helicopters because the majority of their flights are conducted in the airplane mode. Even in the hover mode, the location of the engines and rotors at the end of short wings attenuates rotor-induced vibration.

Noise

Community noise estimates show the tiltrotor to be less noisy than either helicopters or turboprops. Noise that is produced is well within levels permitted by current federal rules. Furthermore, noise generated by a tiltrotor will tend to remain within the vertiport itself (see noise profile of 80 dBA contour—acceptable residential level).

Interior noise levels of the minimum change V-22 are somewhat higher than acceptable for civil certification because of the close proximity of the rotor blades to the fuselage. However, acoustic treatment of the fuselage can reduce the cabin noise to acceptable levels. For the all-new fuselage designs, increased rotortip-fuselage separation allows much lower noise levels inside the aircraft, well below today's standards.

Emissions

Aircraft emission levels were also found to be acceptable. The only potential concern is the tilting nacelle; if engine exhaust is too close to the ground, the heat could cause deterioration of the landing surface over time. This can be remedied with a nozzle mixer or deflector, however, and there is no problem at all with the CTR-1900 and CTR-7500, since these models do not have tilting engines.

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 are 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, OEI detection and compensation, and power sharing between engines.

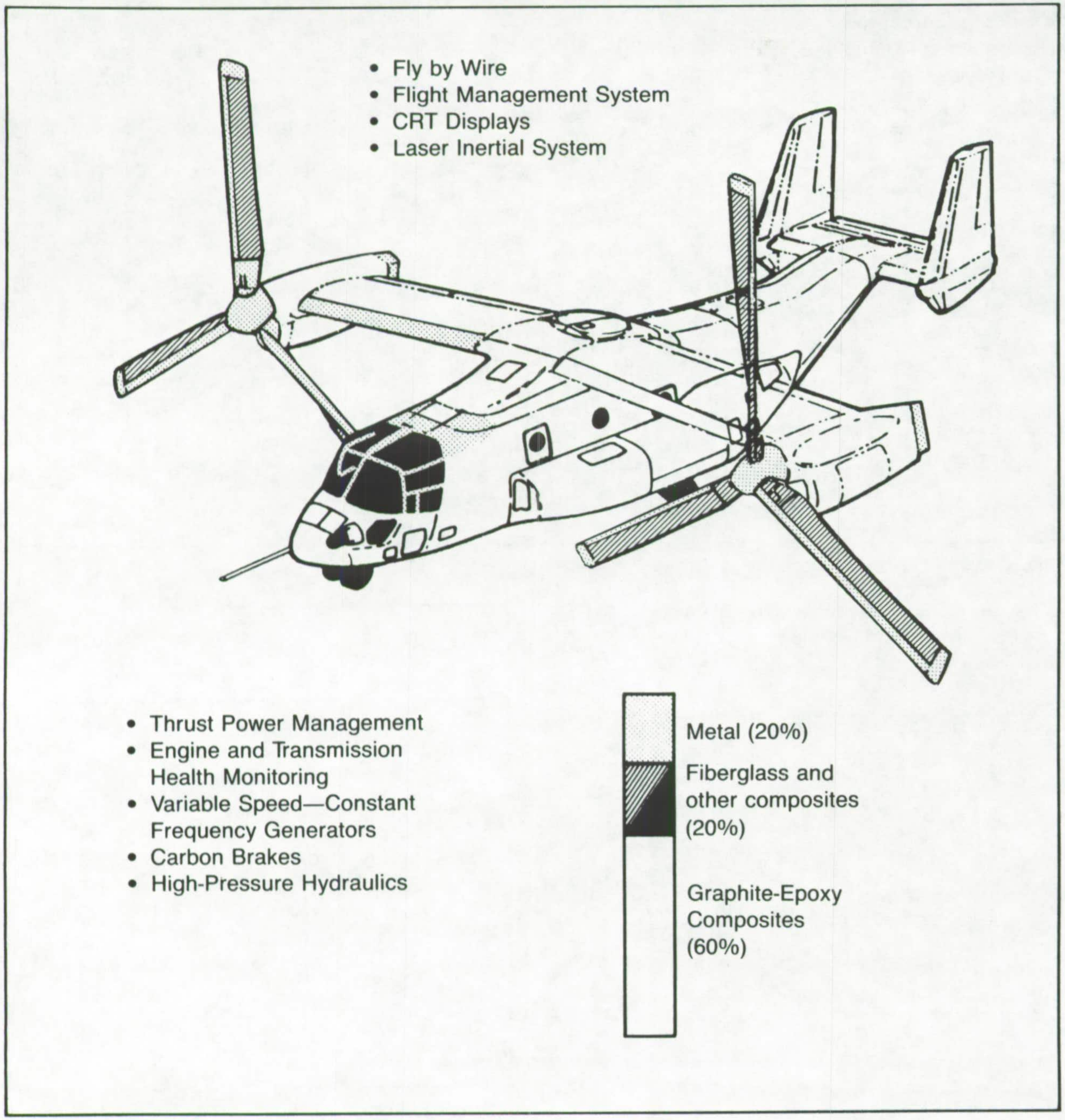
Engine and Transmission Health Monitoring. Sensors on and inside engines and transmission record the operation of critical components and store this information in the aircraft's computer for corrective maintenance. This is a "first" for the rotorcraft industry.

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

Carbon brakes. Lighter, more fade resistant.

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

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



V-22 Technology

Composites. By far the most significant V-22 contribution to the aircraft industry is the dedicated use of composites for reduced weight and increased performance. Shown on the chart below is the impressive amount of structural composites used on the V-22, compared to other civil and military aircraft.

Alloys. New generation aluminum-lithium alloys offer better strength, lighter weight, greater elasticity.

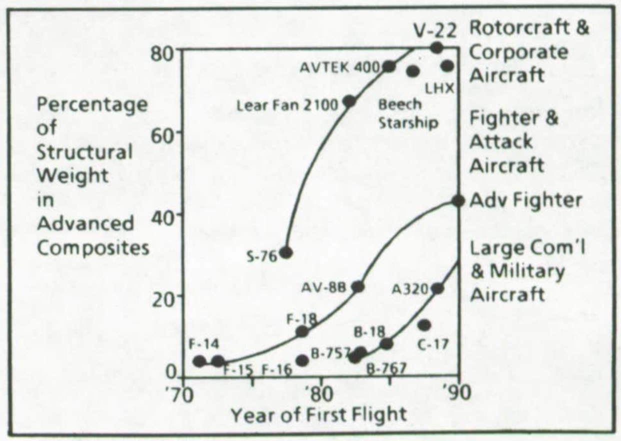
Flight decks. Flat-panel displays, color CRTs, and multi-function displays reduce crew workload, reduce manufacturing and maintenance costs, and improve safety. The V-22 makes extensive use of these new technologies.

Laser inertial systems. Simpler, more dependable, less expensive. The USAF special operations version of the V-22 uses one such system, ring laser gyros.

Ada software. More formal and less ambiguous definition of semantics allows improved correctness and compatibility as well as better code portability. This DOD-promoted language is now being considered as the standard for civil applications.

Data bus. Fewer independent circuits, reduced weight and cost, and increased data for pilots, maintenance monitors, and ground personnel.

Signal/power-by-wire/light. Better safety, decreased weight, maintenance, and costs of ownership.



National Issues

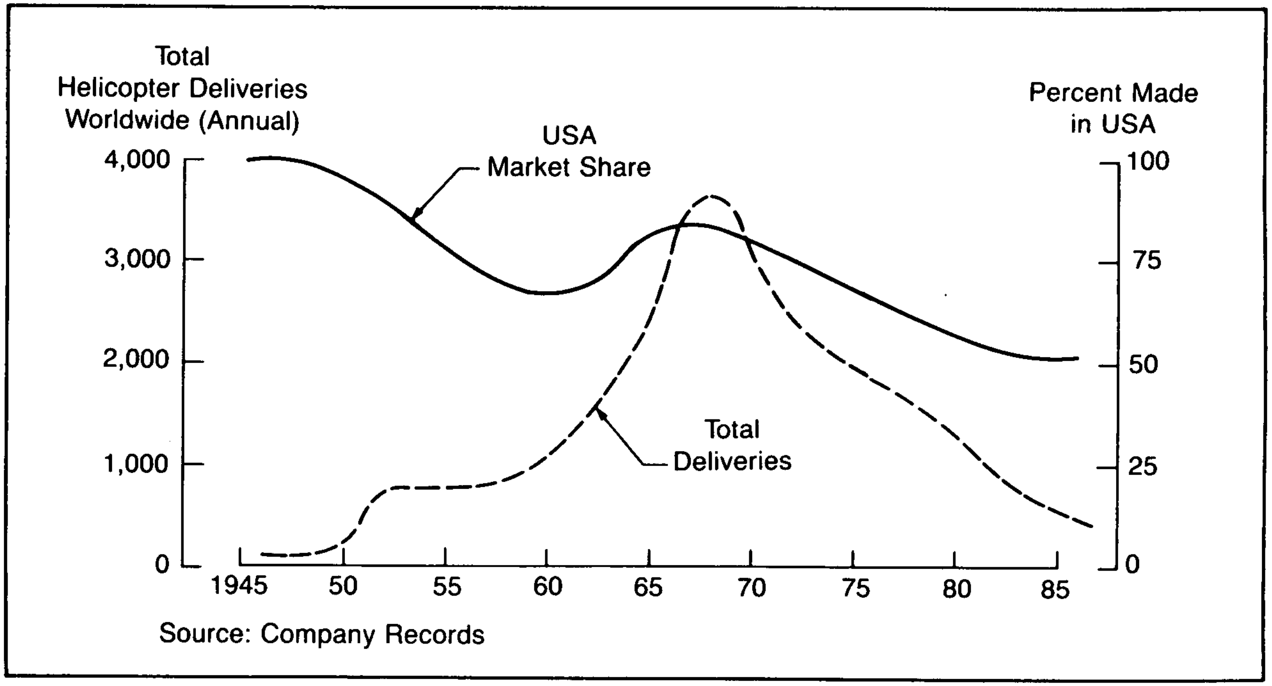
There are two basic forces at the national and international level that appear to have major implications for civil tiltrotor development and related national policy and planning: (1) strong global competition in aerospace market (especially as it relates to balance of trade) and (2) significant congestion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



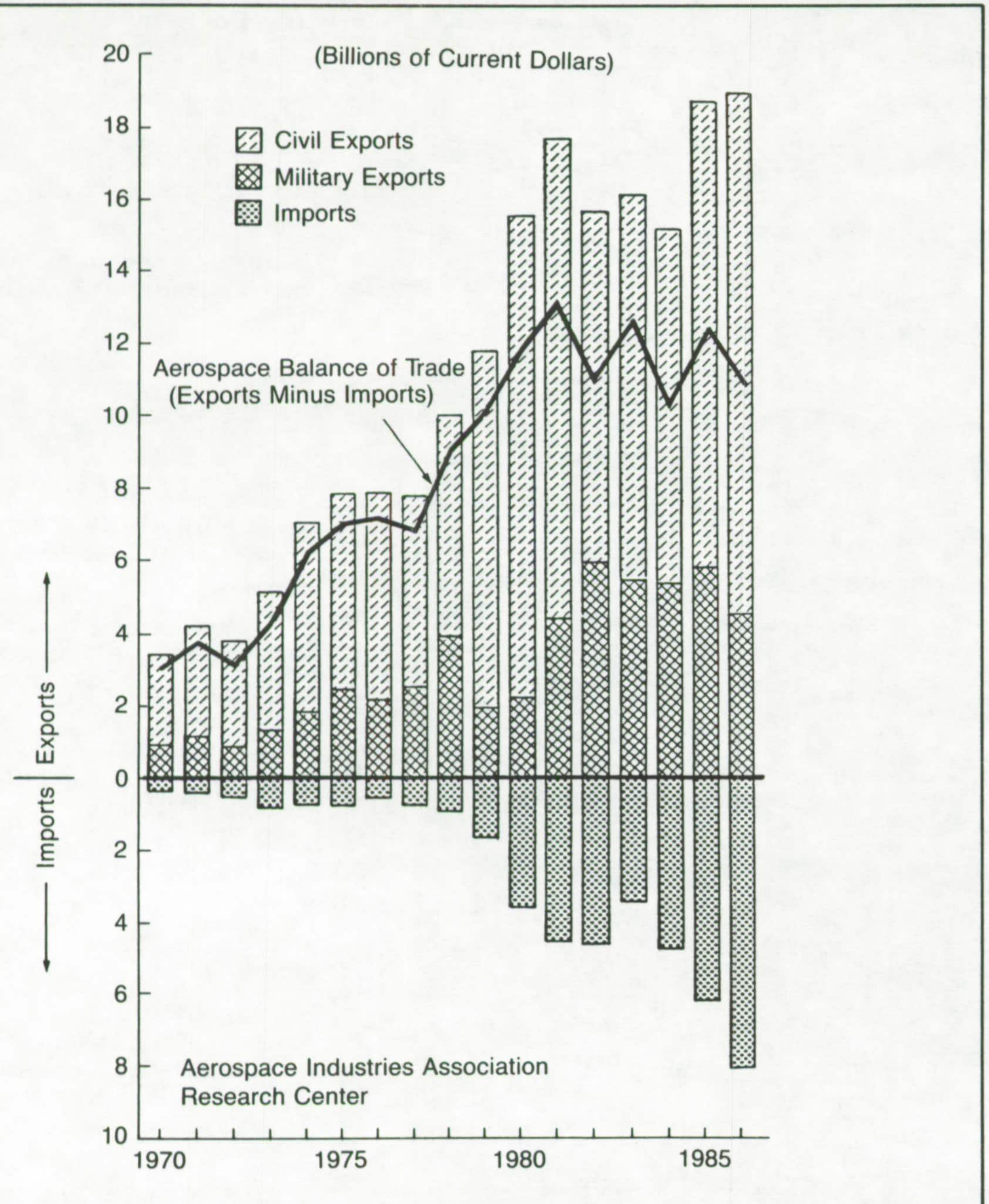
Helicopters

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.

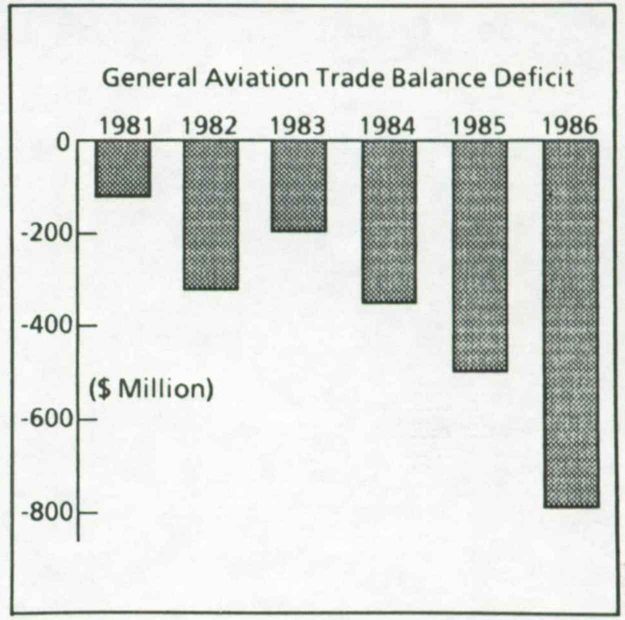
Airport	Delays Per 1000 FLTS
Newark (New Jersey)	143
LaGuardia (NYC)	88
John F. Kennedy (NYC)	75
Logan (Boston)	74
San Francisco	61
O'Hare (Chicago)	51
Hartsfield (Atlanta)	50
Minneapolis-St. Paul	43
Washington National (D.C.)	34
St. Louis	34
US Average	39

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

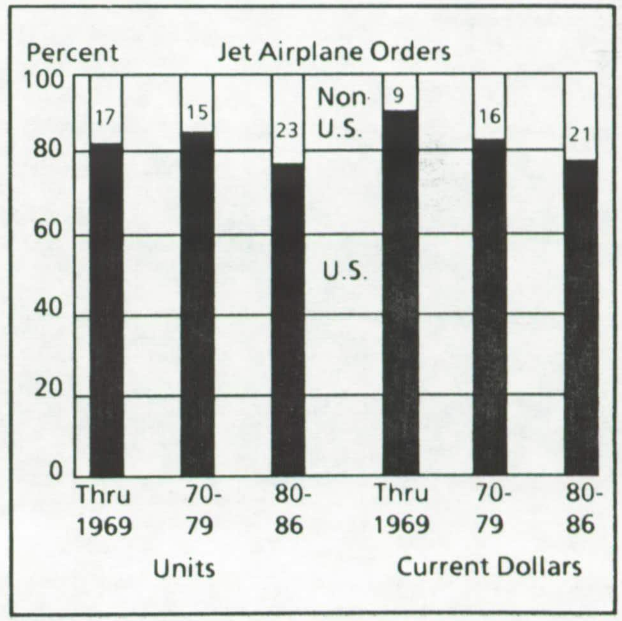
Airport Delays



Trade Balance



General Aviation Trade Balance Deficit



Market Share: U.S. Versus Non-U.S.

NASA National Aeronautics and Space Administration

Report Documentation Page

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16. Abstract

Study examined potential applications of the tiltrotor, specifically V-22 technology, to the civil marketplace. A series of transports were examined, ranging in size from 8 to 75 passengers, with special attention to V-22 derivative designs. The transports were analyzed for applicability and economic viability in several markets: high-density metropolitan, low-density population centers, cargo/package express, public service, and resource development. The study concluded that:

- o the civil tiltrotor is a unique vehicle with a large market potential.
- o the civil tiltrotor is superior to multi-engine helicopters under most conditions.
- o success of the civil tiltrotor depends on the success of the military V-22 tiltrotor.
- o additional work is required to optimize the civil tiltrotor's competitive economics, through application of advanced technology and innovative design.
- o a national civil tiltrotor transportation plan, including suitable infrastructure and a technology demonstration program, is needed.

17. Key Words (Suggested by Author(s)) Air traffic control, balance of trade, certification, civil tiltrotor, congestion, economics, infrastructure, markets, STOL, VTOL, vertiport, V-22 Osprey.	18. Distribution Statement UNCLASSIFIED - UNLIMITED Subject Category: 03		
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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.

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