Rotorcraft Vision

International Powered Lift Conference
Co-sponsored by AHS, AIAA, SAE, Raes
October 30 - November 1, 2000
Hyatt Regency Crystal City
Arlington, Virginia
Features of the Future World Environment

- High time value for travelers and goods
- Demand for rapid, reliable transport
- Increasing urban/suburban land value
- Demand for routine access to remote areas
- Requirements for robust military systems
- Opportunities for advanced technologies
Road transport is no longer a candidate
-Requires valuable land in urban areas
-High capital cost
-Not a high-speed or long-distance solution
-Adverse environmental impact

Rail offers just a partial solution
-Inflexible routes, high capital cost, topographical constraints
-Cost effective only at high traffic densities
-Competes with other uses for land

Fixed-wing air capacity is severely limited by need for runways
-Runway capacity is the bottleneck
-New runways are costly, require valuable land, raise environmental concerns, and have long lead times
-Urban and suburban airports (DCA, LGA, SFO, SJC, MIA, LAX, etc.) will be under great pressure to relocate
Flight Delays Will Worsen Without Corrective Action

Predicted Delay Increase at a Major Hub Airport
Based on MITRE DPAT Model

Number of Aircraft Delayed by More Than X Minutes

Source: Donohue, G., “Investing in Air Transportation Research,” Aerospace America, Sept. 2000, pp. 28-31
Future Rotorcraft Vision

A mix of *vertical lift air vehicles* operating within a *three-dimensional grid* will *revolutionize* air transportation mobility:

- True point-to-point or door-to-door transport
- Complete flexibility of origin and destination
- No need for extensive real estate or large infrastructure investment
- No constraints on system throughput dictated by the need for runways
Vertiport to Vertiport Transportation

Vertiport to Airport Transportation

Simultaneous Non-Interfering Operations at Hub Airports

Just-in-Time Door-to-Door Express and Cargo

Small Air Transportation System Serving Local Airports

Uninhabited Information-on-Demand Surveillance System

Door-to-Door Personal Transport

Intelligent Door-to-Door Air Taxi System

Rotorcraft Vision
Commuter fixed wing aircraft (< 300 nm) carry 20% of the passengers, yet account for 40% of the departures at major hub airports.

Improves terminal area airspace safety and reliability
- Separate corridors and runway traffic for slower aircraft and jet transports
- Improved separation in departure corridors

Increases airport throughput by 25% and reduces delays at airports
- Provides 50% as much delay reduction as a new runway

Commuter fixed wing aircraft (< 300 nm) carry 20% of the passengers, yet account for 40% of the departures at major hub airports.
Projected Operations and Delay at EWR
1997 to 2017

Minutes of delay per operation

Operations

Source: Civil Tiltrotor (CTR) Feasibility Study - Impact at EWR
Runway-Independent Rotorcraft Can Increase System Throughput by 25% or More

Eliminating runway use for short-haul travel increases capacity by 25%

Simultaneous Non-Interfering Operations for trips under 300 miles enable 30% throughput increase at hubs that account for 80% of traffic
AvSTAR
(Aviation Systems Technology Advanced Research)

Enabling Tomorrow’s Air Transportation System

- Runway Productivity
- Surface Congestion Alleviation
- Runway Independent Aircraft Operations
- ATM/TFM Weather Integration
- Improved traffic flow management
- Integrated Airspace Decision Support Tools
- National Traffic Flow Management
- Remove restrictions across facility/sector boundaries
- Reduce separation in the terminal area
- Eliminate surface congestion

AvSTAR
(Aviation Systems Technology Advanced Research)
Rotorcraft Can Sharply Reduce Door-to-Door Time

**Airport to Airport (Fixed Wing)**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speed</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 miles</td>
<td>45 mph</td>
<td>40 min.</td>
</tr>
<tr>
<td>200 miles</td>
<td>400 mph</td>
<td>30 min.</td>
</tr>
<tr>
<td>30 miles</td>
<td>45 mph</td>
<td>40 min.</td>
</tr>
</tbody>
</table>

**Total trip time**
- 200 miles: 185 min.
- 300 miles: 200 min.
+ Delay

**GA Airport/Vertiport to GA Airport/Vertiport (Helicopter)**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speed</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 miles</td>
<td>45 mph</td>
<td>20 min.</td>
</tr>
<tr>
<td>200 miles</td>
<td>200 mph</td>
<td>60 min.</td>
</tr>
<tr>
<td>15 miles</td>
<td>45 mph</td>
<td>20 min.</td>
</tr>
</tbody>
</table>

**Total trip time**
- 200 miles: 130 min.
- 300 miles: 160 min.

**GA Airport/Vertiport to GA Airport/Vertiport (Tiltrotor)**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Speed</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 miles</td>
<td>45 mph</td>
<td>20 min.</td>
</tr>
<tr>
<td>200 miles</td>
<td>300 mph</td>
<td>40 min.</td>
</tr>
<tr>
<td>15 miles</td>
<td>45 mph</td>
<td>20 min.</td>
</tr>
</tbody>
</table>

**Total trip time**
- 200 miles: 110 min.
- 300 miles: 130 min.
Barriers to Achieving the Vision

Key Inhibitors to Expanded Rotorcraft Applications:

- Cost per Seat-Mile or Ton-Mile
- Community Acceptance
- Reliable All-Weather Service
- Perceived Safety
- Passenger Acceptance (Ride Comfort, Speed, etc.)
- Piloting Skill Required
- Infrastructure for 3-D Grid Operation
Effects of Technology Improvement

U.S. Army Future Transport Rotorcraft
20-ton Payload, 300-mile Mission Radius

**1994**
- Gross Weight: 126 tons
- Unit Flyaway Cost: $186 mil.

**2005**
- Gross Weight: 62 tons (-51%)
- Unit Flyaway Cost: $74 mil. (-61%)
Effects of Technology Improvement

Future Transport Helicopter
Percent gross weight/cost reduction by source

1994 - 2005

- Reduction ratios per stage
- Power-to-weight ratio
- Operating/overhaul cost

- Aeromechanics: 31%
- Hover efficiency
- Propulsive efficiency
- Vehicle drag
- Predictive design tools
- Vibratory loads

- Fuel consumption
- Contingency ratings
- Power-to-weight ratio
- Operating/overhaul cost

- Weight reduction
- Advanced materials
- Design optimization tools
- Manufacturing cost
Tiltrotor Noise Reduction Breakthroughs

Typical reductions of 12.5 dB demonstrated in wind tunnel tests

Low-noise approach profiles reduce noise footprint
Rotorcraft Technology Trends

Hover Efficiency

Vibration, g’s

Cruise Speed, km/hr

Empty Weight Fraction

Enhanced crashworthiness, mission equipment, etc.

Tiltrotors

Helicopters
# Long-Range Technology Goals

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>CURRENT LEVEL</th>
<th>2022 TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle Efficiency</strong></td>
<td>Hover Efficiency = 0.78</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>L/D x Prop. Efficiency = 7 at $V_{cruise}$</td>
<td>13 at $V_{cruise}$</td>
</tr>
<tr>
<td></td>
<td>EW Fraction = .55 (helo) -.62 (tiltrotor)</td>
<td>30% reduction</td>
</tr>
<tr>
<td><strong>Cruise Speed</strong></td>
<td>Helicopter = 170 kts</td>
<td>200 kts</td>
</tr>
<tr>
<td></td>
<td>Tiltrotor = 250 kts</td>
<td>Advanced Config. = 350 - 400 kts</td>
</tr>
<tr>
<td><strong>External Noise</strong></td>
<td>External noise metric TBD</td>
<td>Below annoyance threshold</td>
</tr>
<tr>
<td><strong>Vibration &amp; Internal Noise</strong></td>
<td>.05g vibration</td>
<td>Imperceptible (.005g)</td>
</tr>
<tr>
<td>**Intelligent Automation &amp;</td>
<td>Pilot aiding</td>
<td>Operator &quot;directs&quot; vehicle</td>
</tr>
<tr>
<td>Cockpit Integration**</td>
<td>Autonomous flight (UAV)</td>
<td>Autonomous mission optimization</td>
</tr>
<tr>
<td><strong>Reliability &amp; Safety</strong></td>
<td>Reliability metric TBD</td>
<td>Equivalent to fixed-wing airliners</td>
</tr>
<tr>
<td></td>
<td>Accident rate comparable to</td>
<td>Equivalent to fixed-wing airliners</td>
</tr>
<tr>
<td></td>
<td>General Aviation</td>
<td></td>
</tr>
<tr>
<td><strong>All-Weather Operability</strong></td>
<td>IFR-capable</td>
<td>Fully autonomous zero-zero</td>
</tr>
<tr>
<td></td>
<td>Limited icing capability</td>
<td>No restrictions due to icing</td>
</tr>
</tbody>
</table>
Advanced Rotor/Drive System Concepts

Continuous control of shape and airflow achieves near-ideal performance

- Smart material “morphing” blade geometry
- Active blowing and boundary layer modification
- Swashplate-less control
- Active vibration and noise control
- Lightweight rotor construction
- Low-noise geometry
- Reverse velocity airfoils
- Super-safe rotor and drive shaft
- Variable speed, intelligent, self-reconfigurable drive system

Lightweight rotor construction

Reverse velocity airfoils

Variable speed, intelligent, self-reconfigurable drive system

Active vibration and noise control

Super-safe rotor and drive shaft
Bio-Analogous Distributed Systems

Distributed sensors, processors, and actuation devices tailor drag and lift, counter vibration, diagnose faults, and implement corrective action

Active aerodynamic controls

Intelligent operator interface

Self-monitoring, adaptive, reconfigurable, self-healing systems

Distributed sensors, processors, and actuation devices
Advanced Vehicle Configurations

High speed enhances productivity of piloted and uninhabited rotorcraft

Quad Tilt Rotor
Ducted Coaxial Rotor
Folding Prop-Rotor
Canard Rotor / Wing
Personal Transport
“Crashproof” Rotorcraft

UAV technology and smart systems enhance safety and reliability

Environmentally friendly
- Low-noise rotor

Economical
- Low-cost construction
- Affordable propulsion system

Safe and easy to operate
- Smart autonomous self-reconfigurable control system
- Super-safe health & usage monitoring and advanced diagnostics
## INNOVATIVE TECHNOLOGIES

### ATTRIBUTES

<table>
<thead>
<tr>
<th></th>
<th>Intelligent Rotorcraft Systems</th>
<th>Efficient Active Rotor</th>
<th>Revolutionary Configurations</th>
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</thead>
<tbody>
<tr>
<td>Vehicle Efficiency</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Cruise Speed</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Intelligent Automation &amp; Cockpit Integration</td>
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<td>X</td>
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<tr>
<td>Design for Reliability &amp; Safety</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>All-Weather Operability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**X** Primary influence

**x** Secondary influence
Meeting 21st Century air transport needs represents a significant growth opportunity for the rotorcraft community

Rotorcraft can play a key role in the air transportation system of the future ... 

... if they can achieve competitive ticket cost, community acceptance, and passenger comfort

Rotorcraft have improved on many fronts, but the technology is still maturing

A strong research effort will be needed to meet NASA, DoD, and industry goals