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A Vision for Future Civil Rotorcraft

George Price

University of Maryland - NASA Ames Research Center

Abstract

This paper addresses the potential role of rotorcraft—and their designers—in meeting projected needs for transport in the 21st Century. Characteristics of the future world will almost certainly include a premium on travel time, urban growth and consequent increase in land values, need to access remote areas, and robust military systems. Rotorcraft can obviously play an important part in meeting the needs of that world, but only if they can be economical, comfortable, reliable in all weather conditions, safe, and environmentally compatible.

With these advances, rotorcraft can be part of a robust system that provides point-to-point transport with maximum flexibility, low capital costs, and minimum land area. Simultaneous non-interfering rotorcraft operations with fixed-wing aircraft at hub airports will provide complete connectivity and alleviate delays caused by runway congestion. Projections indicate that rotorcraft could indeed possess the necessary attributes in 20 to 30 years, if past trends can be sustained. From 1960 to 2000, rotorcraft have exhibited sharp improvements in such metrics as hover efficiency, cruise speed, vibration, and empty weight fraction. For example, a transport helicopter designed with technologies projected for 2005 would have half the gross weight and a 60% lower unit cost compared to one using 1994 technologies. Active controls, intelligent self-reconfigurable systems, and other advanced technologies that can be identified today hold the promise of achieving this level of improvements, as do innovative configurations that combine hovering efficiency and high speed capability.

Designers will play a leadership role in defining and bringing about the systems of the future by establishing new roles for rotorcraft, formulating innovative design concepts, identifying technology needs, and leading development of future systems.

1 Introduction

This paper summarizes some of the results of a series of NASA-sponsored workshops involving representatives from NASA, US Army, FAA, industry, and academia. The purpose of these workshops was to establish a vision for the future of civil rotorcraft, identify future technology needs, and establish the necessary analysis capability.

2 Future Transport Needs

Figure 1 illustrates projected features of the future world environment as they affect the need for transport. Characteristics of the future world will almost certainly include a premium on travel time, urban growth and consequent increase in land values, need to access remote areas, and robust military systems.

These needs dictate certain characteristics for future transport systems, as illustrated in Figure 2. Rotorcraft can obviously play an important part in meeting the needs of that future world.

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

Figure 1. The future world environment places high value on rapid, flexible transport

21st Century Transport Needs

Future World Needs

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Characteristics of Future Transport Systems

- *Readily accessible, fast, reliable, comfortable, and affordable*
- *Minimum environmental impact*
- *Intermodal connections*
- *Maximum flexibility to adjust to changes in short-term and long-term travel patterns*
- *Minimum land area in populated areas*
- *Serve remote regions as well as urban centers*
- *Serve developing countries with minimal capital investment*

Figure 2. Characteristics of the future world strongly favor rotorcraft transport systems

Although systems involving roads, rails, and runways will still be with us, they offer solutions for only a part of the world's future transport needs. As shown in Figure 3, these modes all require significant real estate and fixed and costly ground facilities.

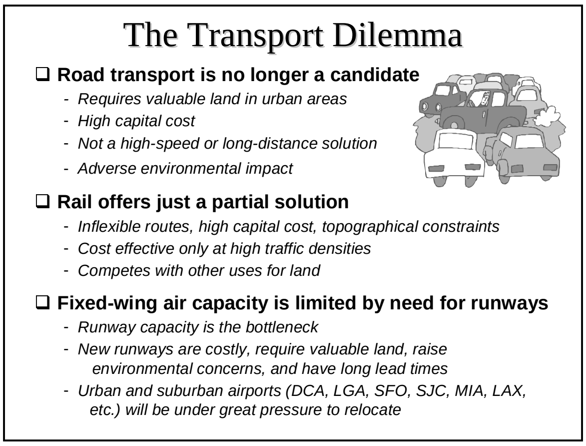

Figure 3. Roads, rails, and runways have severely limited potential

On the other hand, rotorcraft and other VTOL systems offer a superb match for the transport system of the future, as summarized in Figure 4. Most noteworthy is that only vertical lift vehicles can take full advantage of three-dimensional space without the need for large areas on the ground. This characteristic enables true point-to-point transport with maximum flexibility, low capital costs, and minimum ground area.

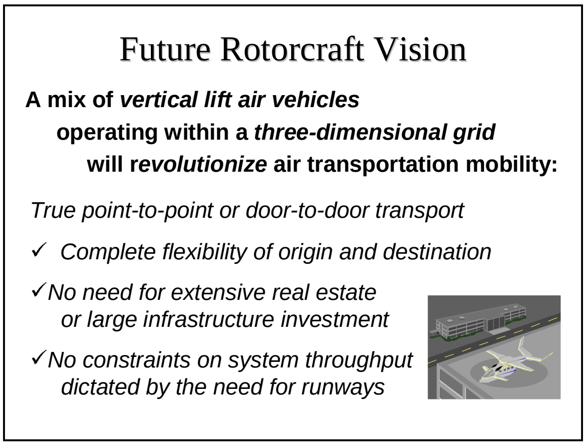

Figure 4. Rotorcraft strongly match future transport needs

Rotorcraft are well poised to meet future needs, but they will succeed only if they can gain passenger and public acceptance that has largely eluded us until now. Thus, significant technology development will be needed to achieve the ticket cost, comfort, reliability in all weather conditions, safety, and environmental compatibility necessary to attract a large proportion of the short-haul passengers typically flying on regional jets today.

With these improvements, rotorcraft can be part of a comprehensive system that responds to the needs of the 21st Century and provides a significant growth opportunity for the rotorcraft community. Figure 5 illustrates a vision that might be achievable.

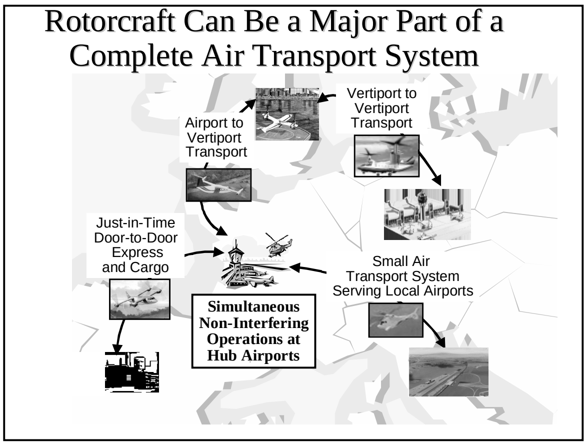

Figure 5. Rotorcraft can be the key to comprehensive future transport service

Rotorcraft operating from existing airports offload runway congestion by substituting for current fixed-wing short haul service; such service could be initiated with a minimal investment in infrastructure, at a fraction of the cost of constructing new runways and without the need to introduce new airfields or vertiports.

Simultaneous non-interfering operation of rotorcraft and fixed-wing aircraft at hub airports provides complete connectivity between the two modes, enabling feeder service from vertiports and small airfields without tying up fixed-wing landing slots. Rapid delivery of high-value cargo to local distribution centers enables just-in-time inventory control and near-immediate response to orders placed through the Internet.

Figure 6 summarizes the key attributes and challenges for developers of rotorcraft technology to overcome the barriers to acceptance. Note that "perceived safety" differs from any calculated safety numbers; perhaps the most important factor affecting public perception is the current and near-past "track record," or how well today's aircraft are doing. For that reason, current safety efforts have a very strong effect on public acceptance of future rotorcraft.

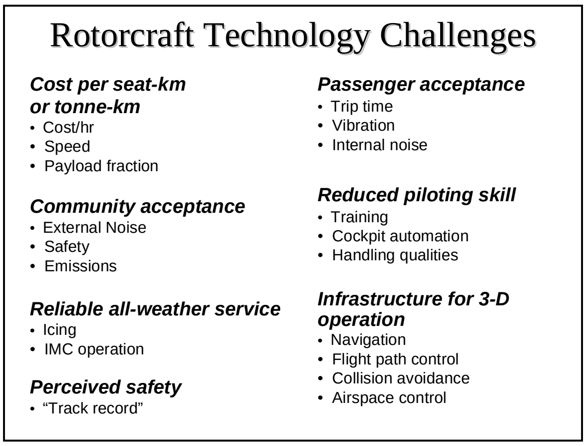

Figure 6. Success in short-haul air transport role poses major challenges for rotorcraft

3 Technology Trends

As illustrated in Figure 7, a variety of technology advances promise to improve rotorcraft performance, reduce cost, and confer other benefits. What will be the effect of these advances, and are they likely to respond to the needs of the marketplace in the coming decades?

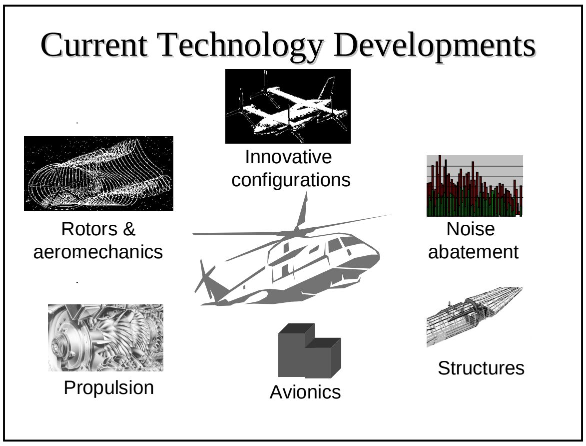

Figure 7. Rotorcraft technology is advancing on many fronts

Figure 8 shows that, from 1960 to 2000, rotorcraft have exhibited sharp improvements in such metrics as hover efficiency, cruise speed, vibration, and empty weight fraction (although improvements in empty weight have been used to compensate for enhanced crashworthiness, increased mission equipment, and other features, rather than to reduce weight). If these trends can be sustained in the coming decades, rotorcraft could indeed possess the necessary attributes.

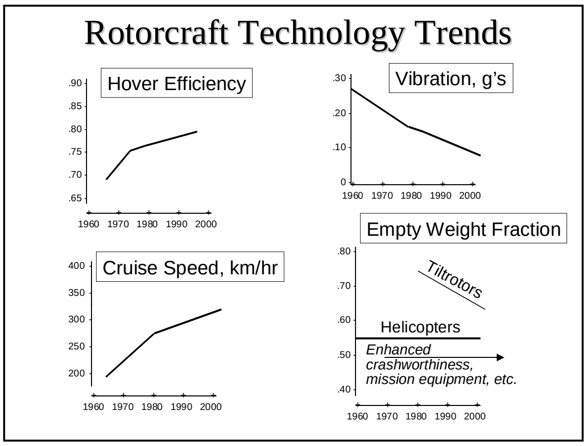

Figure 8. Projected trends establish goals for continued improvement

The effects of technology development can be illustrated by considering a notional helicopter designed for a 500-kilometer radius mission with 18 metric tonnes of payload. According to US Army design studies[1], such a design with 1994 technologies would have a gross weight of 114 tonnes and an estimated unit cost of 195 million euros. As shown in Figure 9, a helicopter designed for the same mission with technologies projected for 2005 would have half the gross weight and cost 60% less, or 77 million euros.

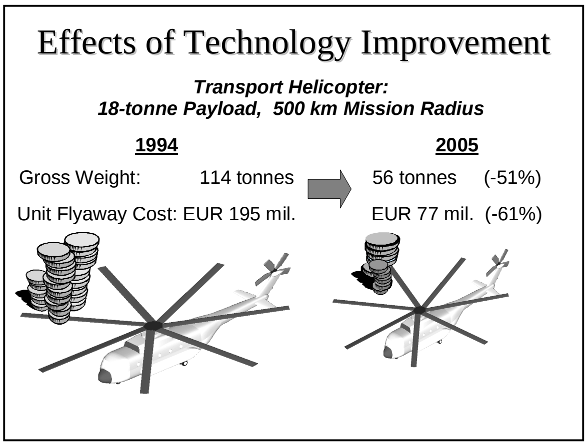

Figure 9. Technology advance shows strong effect on US Army Future Transport Rotorcraft

Figure 10 shows that this results from a variety of technologies. Low cost production methods are a contributor, but the major improvements come from vehicle and engine performance.

[1] Scully, M., "Future Transport Rotorcraft: Parametric Sensitivity Analysis with Mission and Technology Trades," 56th Annual Forum, American Helicopter Society, 2-4 May 2000, Virginia Beach, Virginia

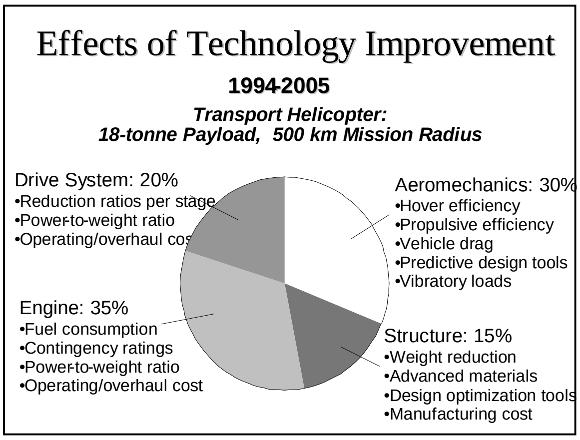

Figure 10. Many technologies contribute to advances in rotorcraft

A combination of projected market needs and technology trends can be used to set targets for future rotorcraft technology attributes. Figure 11 presents suggested targets that should be met if rotorcraft are to make a sizable contribution to the transport system 20 or 30 years from now.

Suggested Key Attribute Targets

ATTRIBUTE	*METRIC*	SUGGESTED TARGET
Vehicle Efficiency	*Hover Efficiency*	10% improvement
	L/D x Prop. Efficiency	85% improvement
	Empty Weight Fraction	30% reduction
Cruise Speed	*Helicopter Speed*	20% improvement
	Advanced Config. Speed	650-750 km/hr
External Noise	*Noise Footprint*	Below annoyance threshold
Passenger Comfort	*Vibration; Internal Noise*	Imperceptible; Normal speech
Intelligent Automation & Cockpit Integration	*Pilot Aiding*	Operator "directs" vehicle
	Autonomous Flight (UAV)	Self-reconfiguration
Reliability & Safety	*MTBF, MTTR, etc.*	Equivalent to fixed-wing
	Accident Rate	Equivalent to fixed-wing
All-Weather Operability	*IFR Capability*	Fully autonomous zero-zero
	Icing Capability	No restrictions due to icing

Figure 11. Suggested targets for rotorcraft technologies respond to future needs

Figure 12 shows the effect of major drivers affecting the cost of carrying passengers or cargo. Based on fundamental relationships, rotorcraft transport today costs six times as much as fixed wing aircraft. This is somewhat — but far from completely — compensated for by lower costs related to airports, terminals, and other elements, and often by operating with low overhead costs. However, if future rotorcraft can meet the suggested targets, the disadvantage relative to fixed-wing aircraft is reduced from a factor of six to 30 percent, a disadvantage that can easily be overcome by the much lower ground costs associated with rotorcraft.

The projections in Figure 12 allow for improvement in fixed-wing technology, but the allowance is smaller than the projected improvement in rotorcraft. The difference reflects the fact that rotorcraft technologies are less mature: the theories are less comprehensive, effects and interactions are more complex and not as well understood, and rotorcraft development has not been as intensively funded.

Another way of considering this projected cost reduction is to compare it to the previously presented US Army analysis. That study showed rotorcraft cost shrinking by approximately 50 percent in ten years. If this trend can be sustained, it would result in a fourfold reduction in 20 years, which corresponds roughly to the projections in Figure 12.

Advanced Technologies Will Enable Rotorcraft to Achieve Competitive Cost

Major Drivers of Direct Operating Cost per Available Seat Km (DOC/ASKM) Relative to Fixed Wing Short Haul Airliner

Parameter	Current Rotorcraft vs. Fixed Wing	*Rotorcraft Improvement Target*	Rotorcraft Target vs. Fixed Wing (1)
Block Time	180%	*-50%*	Equal
Forward Flight Power Required	200%	*-50%*	120%
Flyaway Cost	150%	*-40%*	110%
Maintenance Cost	300%	*-60%*	150%
Empty Weight/ Gross Weight Ratio	115%	*-30%*	Equal
Relative DOC/ASKM (based on above)	**600%**		**130%** (2)

(1) Assumes 33% Fixed Wing DOC/ASKM improvement 2000 - 2025

Figure 12. Technology targets enable rotorcraft to be cost-competitive with fixed-wing aircraft

4 Candidate Technologies

Can these projected improvements really be achieved? Applicable technologies that can be identified today include distributed intelligence and adaptive self-healing systems, as illustrated in Figure 13.

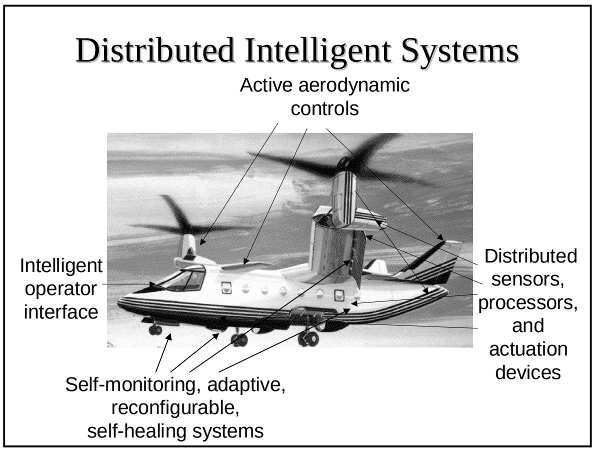

Figure 13. Distributed intelligent systems tailor drag and lift, diagnose faults, and implement corrective action

Similarly, future rotors will benefit from active controls, variable geometry, applications of smart materials, and other advanced technologies shown in Figure 14.

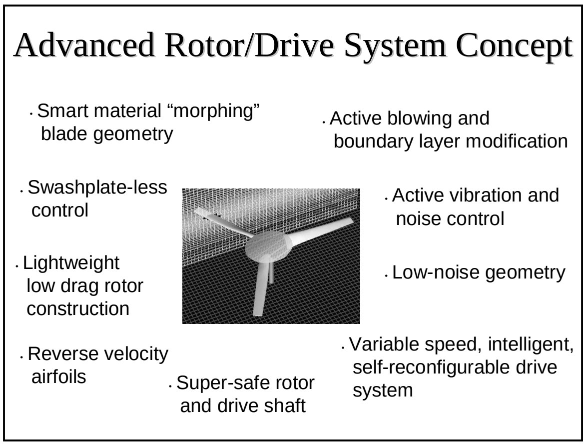

Figure 14. Continuous control of shape and airflow achieves near-ideal performance

Personal mobility will be enhanced by intelligent operator interfaces, self-reconfigurable systems, low cost design and fabrication, and other technologies shown in Figure 15. Emerging technologies for reliable autonomous uninhabited air vehicles will no doubt contribute to the safety of piloted vehicles as well.

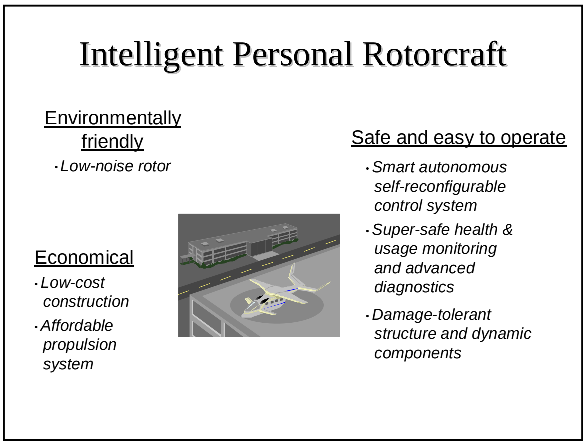

Figure 15. Advanced technologies enable economical "crashproof" personal mobility

Figure 16 depicts some innovative vehicle concepts being studied or developed today. All other things being equal (which they never are), cost per seat mile is inversely proportional to speed; hence the continuing search for configurations that combine the vertical flight efficiency of the helicopter with the forward flight efficiency of fixed-wing aircraft.

The technologies shown in Figures 13, 14, and 15 are fully applicable to these configurations.

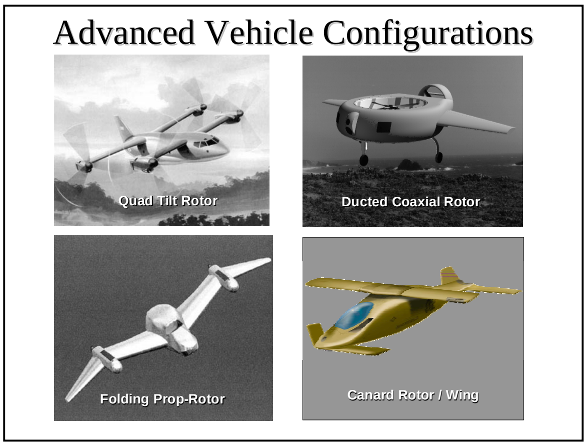

Figure 16. Innovative configurations seek to combine high speed with efficient vertical flight

5 The Designers' Role

The talent, leadership, and technical toolkits of the design community will to a large extent set the path for development of future technologies, vehicles, and transport systems. Figure 17 illustrates the vital role that designers will play, as well as the challenges that face bold innovators who will lead us to this vision.

What Must Be Done

1. Define and rationalize the role of rotorcraft in the transport system of the future
2. Define the design concepts that can provide the attributes needed for this role
3. Identify and develop the technologies that will achieve the necessary attributes
4. Development the infrastructure that will enable rotorcraft to perform in the selected role
5. Develop the market and the rotorcraft to meet market needs

Figure 17. Designers will have a key role in developing the transport systems of the future

It will not be enough, however, to design technically advanced vehicles — to succeed in the market place, the rotorcraft of the future must also be attractive to a prospective passenger in terms of ticket price, convenience, comfort, all-weather reliability, and perceived safety.

6 Conclusions

Conclusions that can be inferred from this discussion include the following:

- Rotorcraft offer an excellent match for future transport needs *if* they can achieve competitive ticket cost, passenger acceptance, and environmental compatibility.
- Meeting 21st Century air transport needs constitutes a significant growth opportunity for the rotorcraft community.
- Rotorcraft have improved on many fronts, but the technology is still maturing — technology advances from 1994 to 2005 result in a doubling of cost effectiveness for a representative transport mission.
- If past trends can be sustained, continuing advances in key technologies will achieve the necessary attributes of efficiency for affordable ticket cost, low noise for community acceptance, reliability in all weather operation, safety, passenger comfort, automation, and efficient use of air and ground space.
- Designers will play a leadership role in achieving this vision of the future of civil rotorcraft.

The ultimate criterion for success will be passenger acceptance of economical, reliable, comfortable, environmentally compatible rotorcraft service.