PAPER Nr.: 59

IMPACT OF NEW TECHNOLOGY VTOL DESIGNS IN THE CIVILIAN FIELD

by

Jaan Liiva
Director, Sales and Marketing Analysis
Boeing Vertol Company
Philadelphia, Pennsylvania
United States of America

FIFTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM
SEPTEMBER 4 – 7TH 1979 - AMSTERDAM ,THE NETHERLANDS

IMPACT OF NEW TECHNOLOGY VTOL DESIGNS IN THE CIVILIAN AVIATION FIELD

Jaan Liiva
Director, Sales and Marketing Analysis
Boeing Vertol Company
Philadelphia, PA

INTRODUCTION

The requirement to support oil drilling and production platforms in the North Sea by dependable, around the clock transportation has given the helicopter manufacturers and users the opportunity to develop and produce improved large helicopters, such as the S-61, the Puma, and the Chinook, to the point where high utilization, IFR capability and high safety standards are no longer a dream but reality. As large helicopters prove their reliability and safety of operation in the oil support market segment, they offer the potential of participating in the commercial, short-haul passenger transport market.

Figure 1 shows the number of passenger miles flown by fixed-wing aircraft between city pairs in the U.S. at distances of 300 miles or less as compared to the estimated helicopter traffic in the North Sea. If large helicopters can capture just 10% of the North American market, the number of helicopters in passenger service would be five times those used in the North Sea. Worldwide the potential is larger

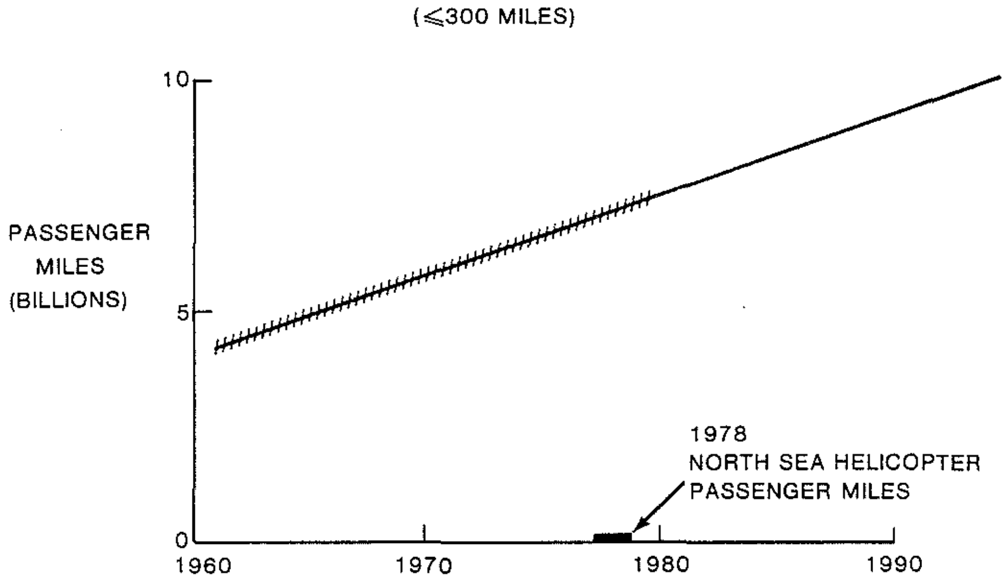

Figure 1. U.S. Fixed Wing Short Haul Passenger-Miles Growth

still and helicopter pioneers like Jock Cameron of BAH are looking forward to scheduled passenger operations in the mid 80s first with a stretched 60-plus passenger Chinook and later with a 200-plus passenger heavy-lift helicopter based on the United States Army YCH-62 program.

Perhaps most important, the large helicopter can reduce airport congestion and eliminate the long taxi, car or train ride at both ends of the trip. Figure 2 shows that helicopters can reduce travel time between city centers as far as 400 miles apart. The combination of convenience, new levels of passenger comfort, favourable operating economies, and reduction of airport congestion gives the large helicopter a prime potential for capturing part of the large short-haul passenger market.

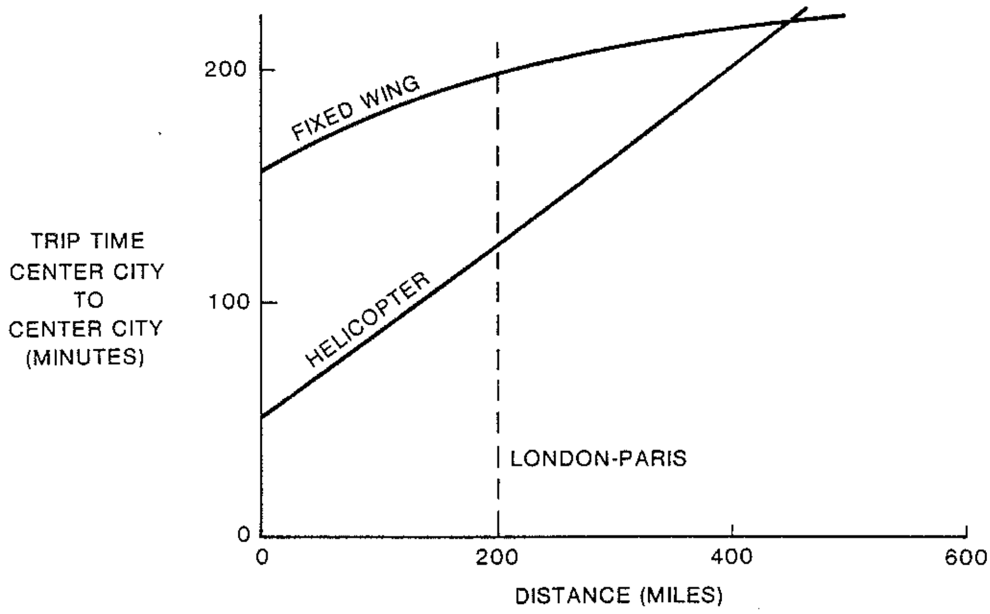

Figure 2. Helicopter Versus Fixed Wing Block to Block Elapsed Time

The faster speed VTOLs, such as compounds, tilt rotors, helijets and possibly lift fan aircraft are seen as a second generation of capability, to consolidate the gains secured by the large helicopters and expand the range from 200-300 nautical mile non-stop segments to 400-600 nautical miles. Their timing, due to the research and development required, will lag helicopters by 8 to 10 years unless a major, concerted nationally sponsored priority program is set up to develop VSTOLs more rapidly. The concepts and technology investigations supporting the configurations in this study are well underway, and in the case of the ABC compound and the tilt rotor are already in prototype flight test status.

This paper looks at the possibility of converting the notional V/STOL aircraft (Figure 3) designed by Schoen and Peck (1) for the U.S. Navy and Marine Corps missions to scheduled passenger and utility configurations. The reason for combining the commercial and the military requirements is obvious; the research, development, and certification program can be amortized over a much larger production base and the risk of development shared by both the military and the civilian sectors. In addition, there is a decided advantage to the U.S. DOD, since in wartime, the civil aircraft can be directly used for military transport missions with a minimal impact on the logistics supply and training requirements. NASA Ames Directorate and the U.S. Navy (2,3,4) are providing this impetus to the United States effort, and we in the industry welcome the foresighted, systematic planning of NASA (5,6,7,8) to achieve these national goals.

In this paper we will describe the differences between the military and civil configurations and calculate the operating economies as a function of stage length. Noise and public acceptance of downtown airports are also discussed.

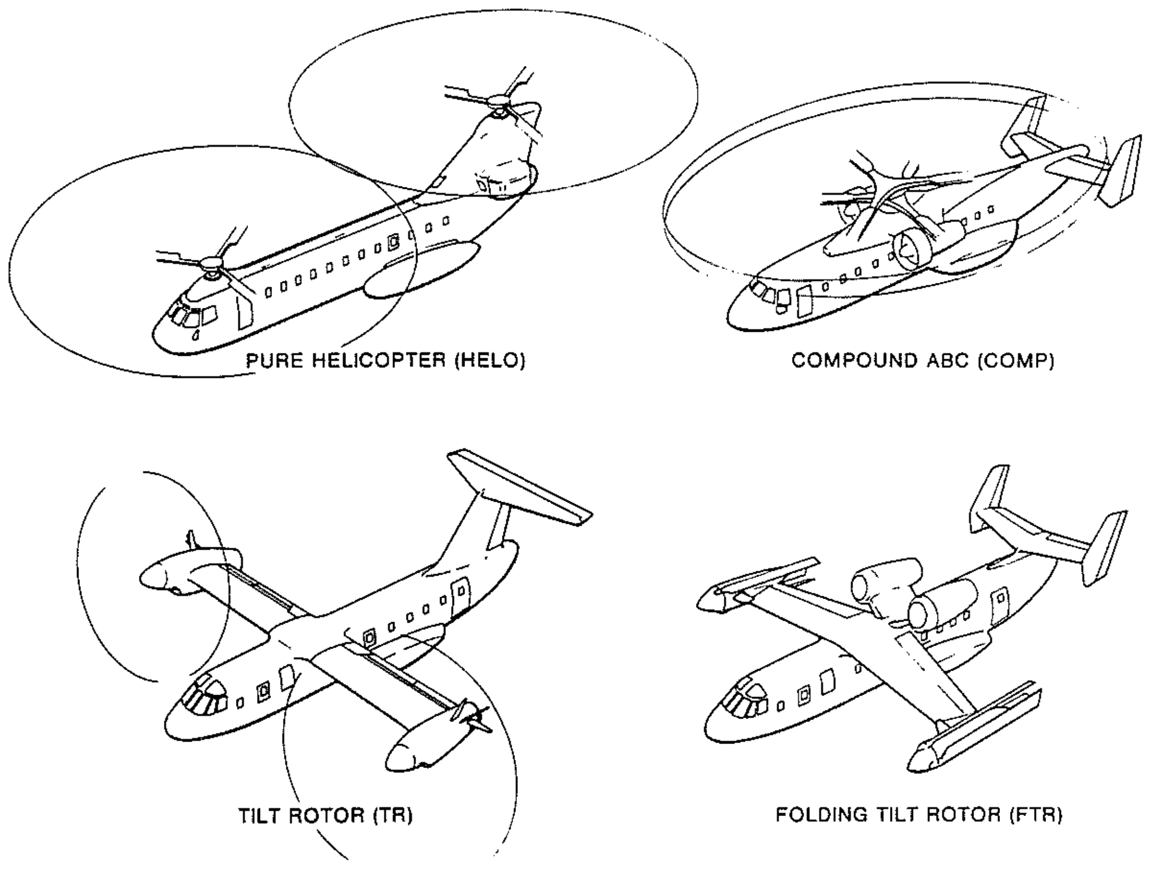

Figure 3. Commercial V/STOL Study Configurations

AIRCRAFT CONFIGURATION DESCRIPTION

The aircraft compared in this study (shown in Figure 3) are a Pure Helicopter, a Compound (ABC type) Helicopter, a Tilt Rotor and a Folding Tilt Rotor. All of these aircraft were designed for the U.S. Navy's multi-mission-support airplane requirement, V/STOL A. The Tilt Wing and Lift Fan were also presented in the earlier paper, but will not be studied here because there is very small performance difference between the Tilt Rotor and Tilt Wing and the Folding Tilt Rotor and Lift Fan. In both cases we chose the lower disc-loading aircraft to minimize downwash and noise for center city passenger operation. In addition, the propulsion package location of the military Lift Fan configuration precludes providing a commercial fuselage with adequate window and door locations. For commercial use the propulsion units would have to be located out on the wing, rather than shoulder mounted on the fuselage.

All aircraft are designed to the "Accelerated Technology Development" level described in Reference 1, presented in Reference 9, and shown in Figure 4. A few points were also calculated to current levels of technology to show the spread of data from present levels to the accelerated levels. In all cases the basic Navy design aircraft were used directly with only the following changes:

- All armor plate and fuel system ballistic protection were deleted.
- Navy/Marine Corps interior and avionics were deleted.
- The Cabin was stretched by 10 feet to accommodate 44 passengers in the Tilt Rotor and Folding Tilt Rotor and 48 passengers in the Helicopter and Compound.

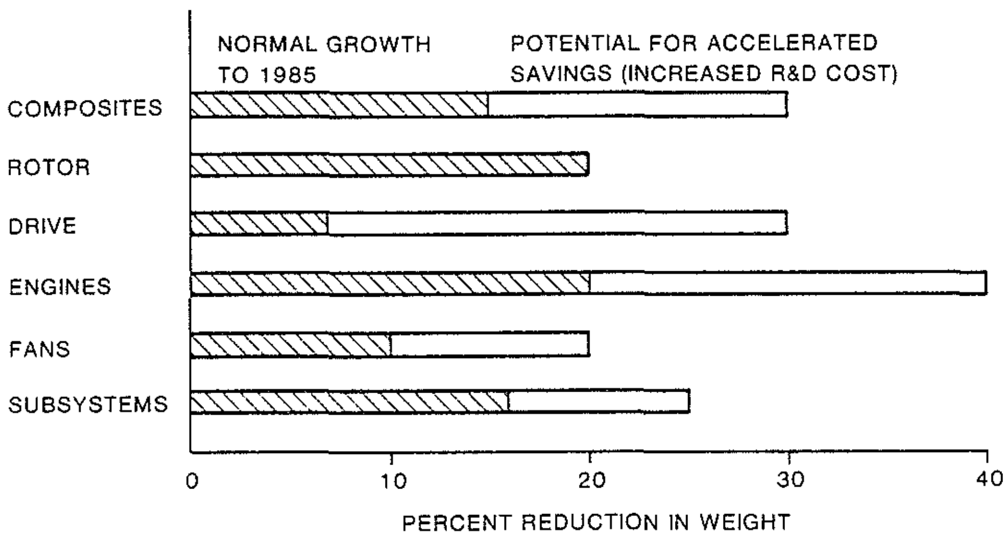

Figure 4. Projected Technology Savings

- Commercial interior (including galley, lavatory and air conditioning), IFR avionics and the electrical system were changed to civil requirements.

Other ground rules for these commercial studies are:

- Hover takeoff at sea level, 90°F with FAA ground rules for enroute engine out requirements.
- Cruise at 2,000 feet for the Helicopter and Compound and 10,000-25,000 feet for the Tilt Rotor and Folding Tilt Rotor, depending on range, to maximize fuel economy during wing-borne flights.
- Fuel tanks were sized to permit approximately 500 nautical miles of flight including reserves, but no effect of headwinds.

Since the military aircraft engines in Reference 1 were primarily sized by the midpoint hover of 3,000 feet, 91.5°F criterion, we were able to add the 10-foot stretch and the extra passengers at the sea-level, 90° takeoff condition without changing the dynamic system characteristics, thereby minimizing the cost impact on the commercial aircraft.

Weight, horsepower and maximum continuous power airspeed envelopes are shown in Figures 5 and 6 for the candidate aircraft as a function of airspeed and altitude. It is clear from these figures that high levels of performance demand large high-powered aircraft and that the winged aircraft fly faster and more efficiently at higher altitudes. Also evident are two separate trends – one for the Helicopters and Compounds (edgewise flyers) and one for the more efficient Tilt Rotor and Folding Tilt Rotor.

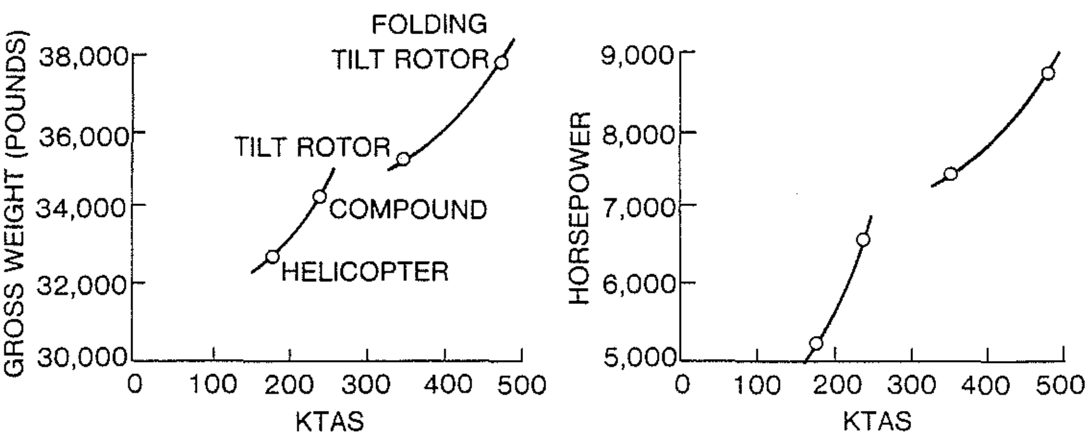

Figure 5. Relationship of Performance to Size

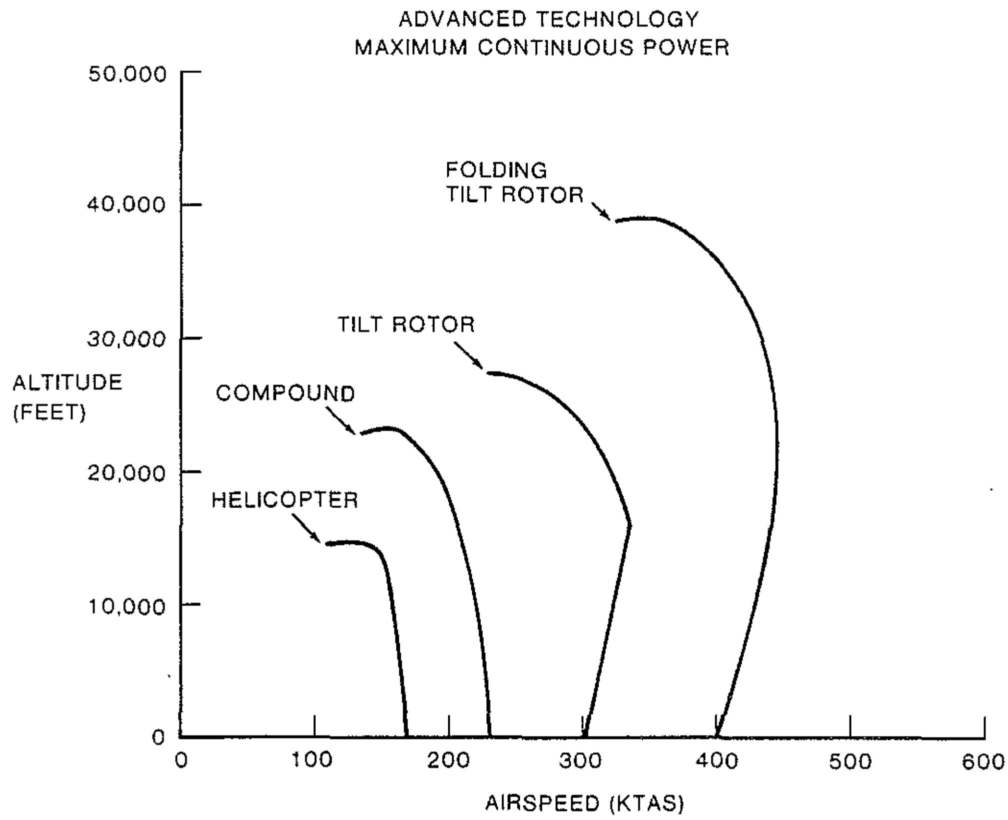

Figure 6. Comparison of Flight Envelopes

The effect of normal growth to 1985 and advanced technology level on gross weight is shown in Figure 7 for all aircraft. Included is a band representing today's technology. The reduction in takeoff gross weight over normal growth technology is approximately 15% for the Helicopter, Compound and Tilt Rotor. The reduction is greater for the Folding Tilt Rotor due to a greater effect from composites and the drive system.

The lifting capability and hover endurance of the candidates are shown in Figure 8 for utility missions. The results are highly influenced by the performance characteristics of the aircraft, i.e., the Helicopter with relatively low disc loadings and high mission fuel capacity has substantially better lift capability and hover endurance than the other candidates. The Tilt Rotor type aircraft have relatively higher empty weights, lower fuel capacity due to better cruise efficiency and higher disc loadings for optimum design and therefore have lower lifting and hover endurance characteristics. In the next section we shall show how the payload characteristics and operating costs combine to provide relative measures of effectiveness for the various aircraft.

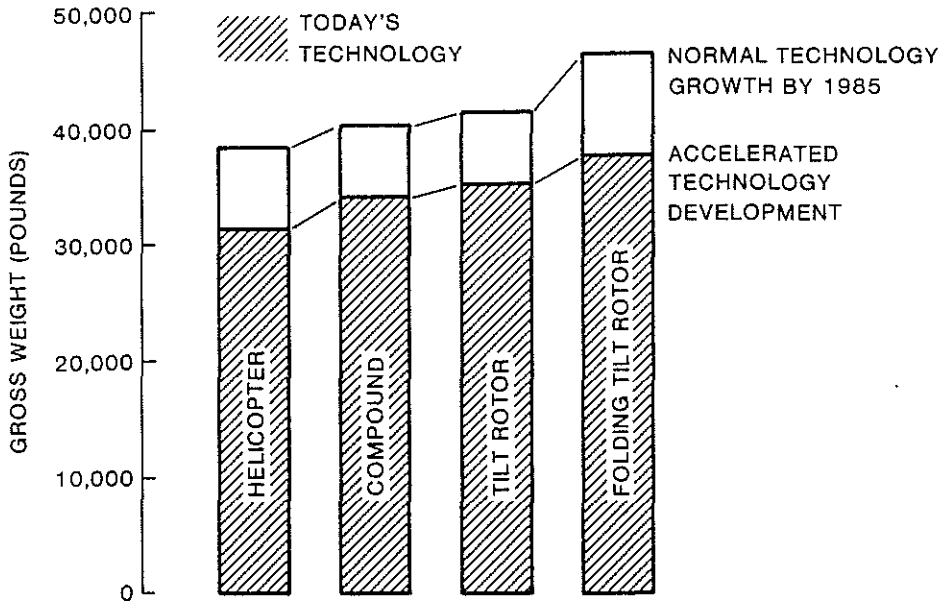

Figure 7. Effect of Technology Level on V/STOL Size

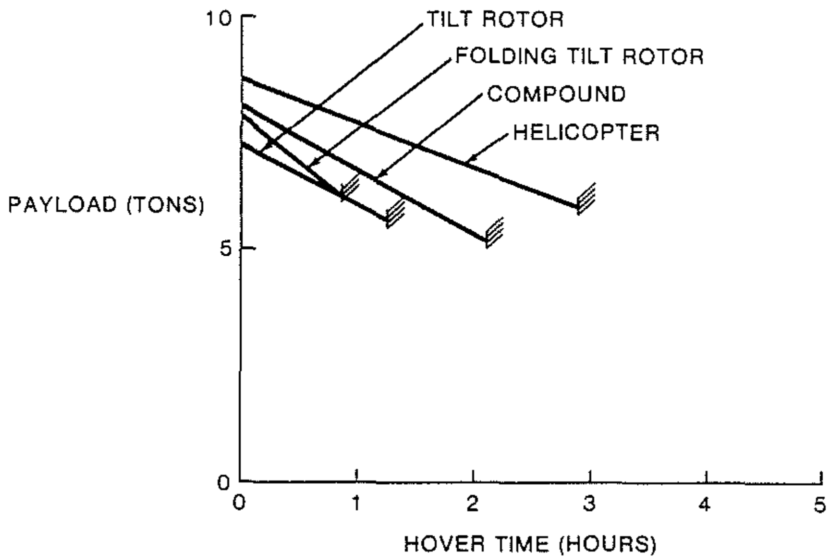

Figure 8. Lifting Capability for Utility Missions

COST OF OPERATION

As aircraft size increases, development cost, production cost and operating cost increase. However, as speed or altitude capability increases, the aircraft become more productive and the fleet size can be reduced or the effective range increased for increased revenue. Since the commercial and the military aircraft are produced from the same basic design and share approximately 80% of the components, the certification program will be structured to gather data to meet both programs, with separate additional testing for the peculiar configuration features of each type. The following cost ground rules were used:

RESEARCH AND DEVELOPMENT COST

- Two manufacturer competitive fly-off for military
- Simultaneous development of configurations for military and commercial aircraft by winner of fly-off
- Simultaneous testing of components to either military or civil specification, whichever is more stringent
- Simultaneous testing of prototypes to provide both civil and military certification data where possible

PRODUCTION COST

- Common production line for civil and military derivatives to minimize tooling and labor costs
- Simultaneous buy of common equipment to minimize materiel cost

A commercial production run of 500 aircraft was assumed for a 10 to 15 year period for each of the configurations. Commercial missions include passenger transport for both charter type operations, such as oil rig support, and inter- and intracity transport; utility missions include the internal and external lifting and carriage of cargo and equipment. The total production run is based on the combined military and civil versions and range from 1,329 for the Helicopter to 1,100 for the Folding Tilt Rotor.

The direct operating cost, in U.S. dollars per available seat mile, including fuel, maintenance and maintenance burden, crew pay, insurance and depreciation on equipment and spares was calculated using a highly modified AIA 1967 formula and is shown for the four candidate aircraft in Figure 9. The corresponding payload-range data are shown in Figure 10. The Helicopter and Compound have comparable seat mile costs with the Compound slightly higher. The Compound is heavier and has larger engines and fuel flow. This increases the acquisition cost and also the cost of operation. The Compound also has a sharp upturn in the operating cost at 350 miles, caused by the requirement to offload passengers beyond this point. If a full 500 nautical mile range would be required, the Compound would have to be re-sized with more power for a greater payload capacity. This would further increase the operating cost and would require additional differences between the military and commercial versions. The Tilt Rotor and Stowed Tilt Rotor have essentially comparable seat mile costs, with the Tilt Rotor slightly better at ranges below 225 nautical miles. Tilt Rotor type aircraft operating costs are approximately 10 to 15% lower than the Helicopter and Compound.

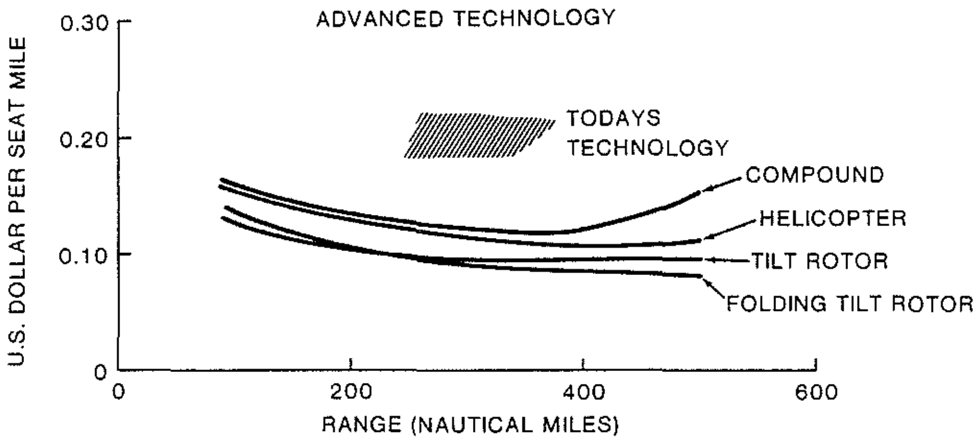

Figure 9. Direct Operating Cost

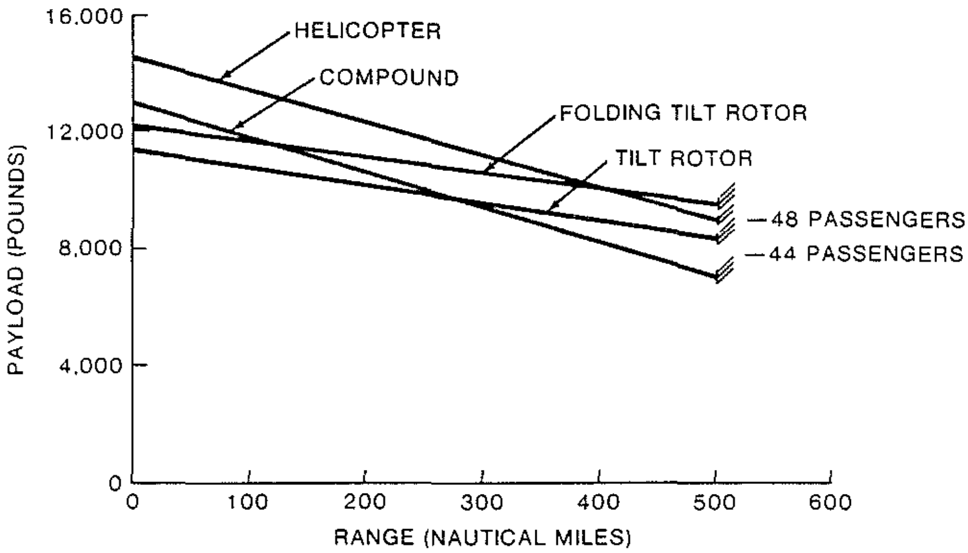

Figure 10. Payload Range Characteristics

We also investigated the effect of using the "normal growth to 1985" technology level on the operating economies. The seat mile costs were 10 to 15% higher for these cases and the relative rankings were unchanged. The seat mile costs of present technology level helicopters are also shown for comparison.

Based on the lifting capability shown earlier in Figure 8 and the cost of operation per hour, the relative cost of external load carriage is shown in Figure 11 for logging and utility lifting type missions in normalized ton-nautical miles of lift per dollar.

Since the Compound, Tilt Rotor and Folding Tilt Rotor do not benefit from their greater speed capability in this type mission, the Helicopter outranks the higher speed aircraft by a wide margin. It is highly unlikely that the Compound, the Tilt Rotor and the Folding Tilt Rotor can compete for utility missions such as logging and construction due to their greater complexity and cost of operation.

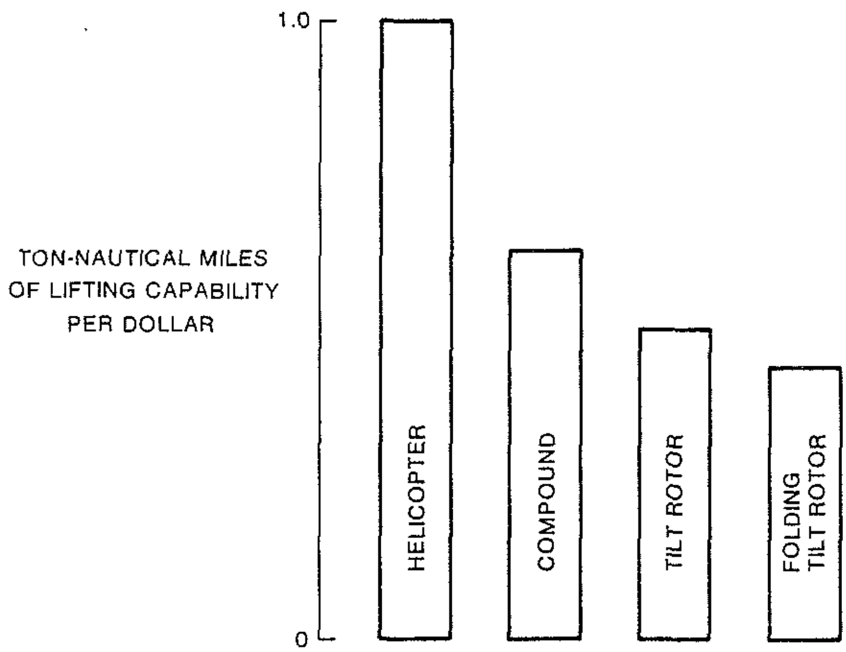

Figure 11. Relative Operating Cost for Utility Missions

V/STOL FLIGHT CORRIDORS

The FAA has established a "Northeast Corridor" IFR route in the U.S. (Reference 10, Figure 12) from Washington, D.C. to Boston, Massachusetts via Philadelphia and New York City with numerous feeders, spurs and instrument approach procedures. The altitude for these routes have a minimum as low as 1,700 feet above ground level to a maximum authorized altitude of 5,000 feet. The Helicopters and Compound Helicopters discussed in this paper could be flown IFR in this corridor right now. To operate the Tilt Rotors and Folding Tilt Rotors efficiently, the optimum altitude for routes longer than approximately 100 miles will be above 10,000 feet, and a new set of procedures and equipment would have to be worked out to enable the high performance aircraft to operate in the regular fixed-wing air traffic control environment enroute with a hand-off to the V/STOL control system for terminal area operations. Similar corridors are needed in other potential operating areas such as London/Paris/Brussels/Amsterdam (Figure 13) to provide the direct point-to-point flight corridors needed for compatibility with V/STOL operations.

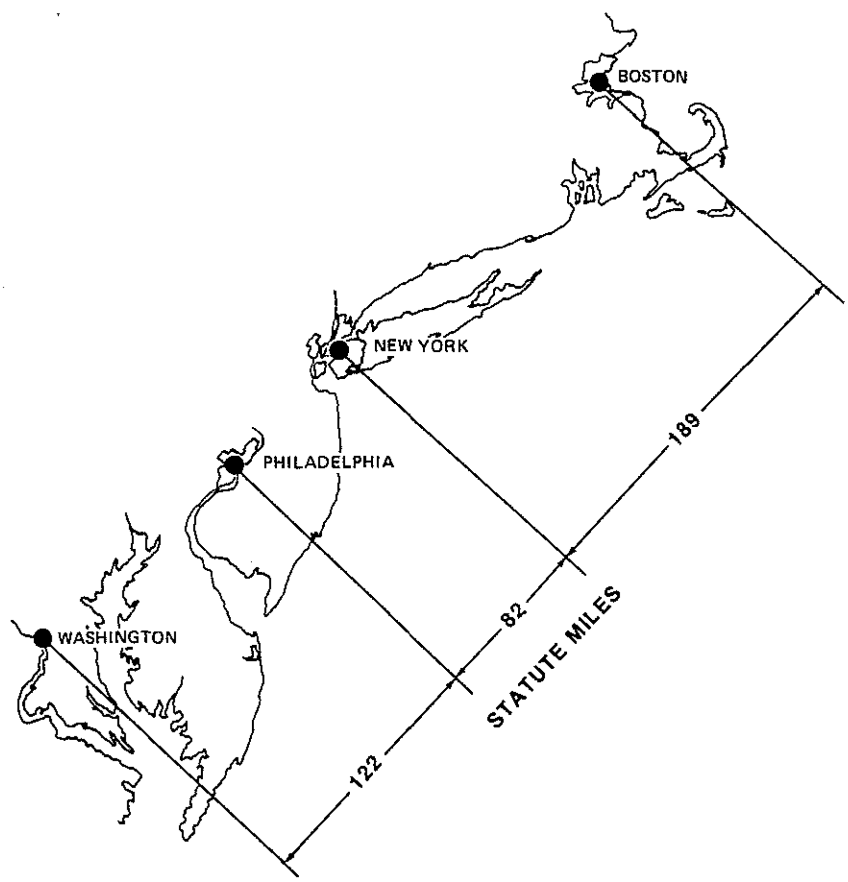

Figure 12. Northeast Corridor IFR Route

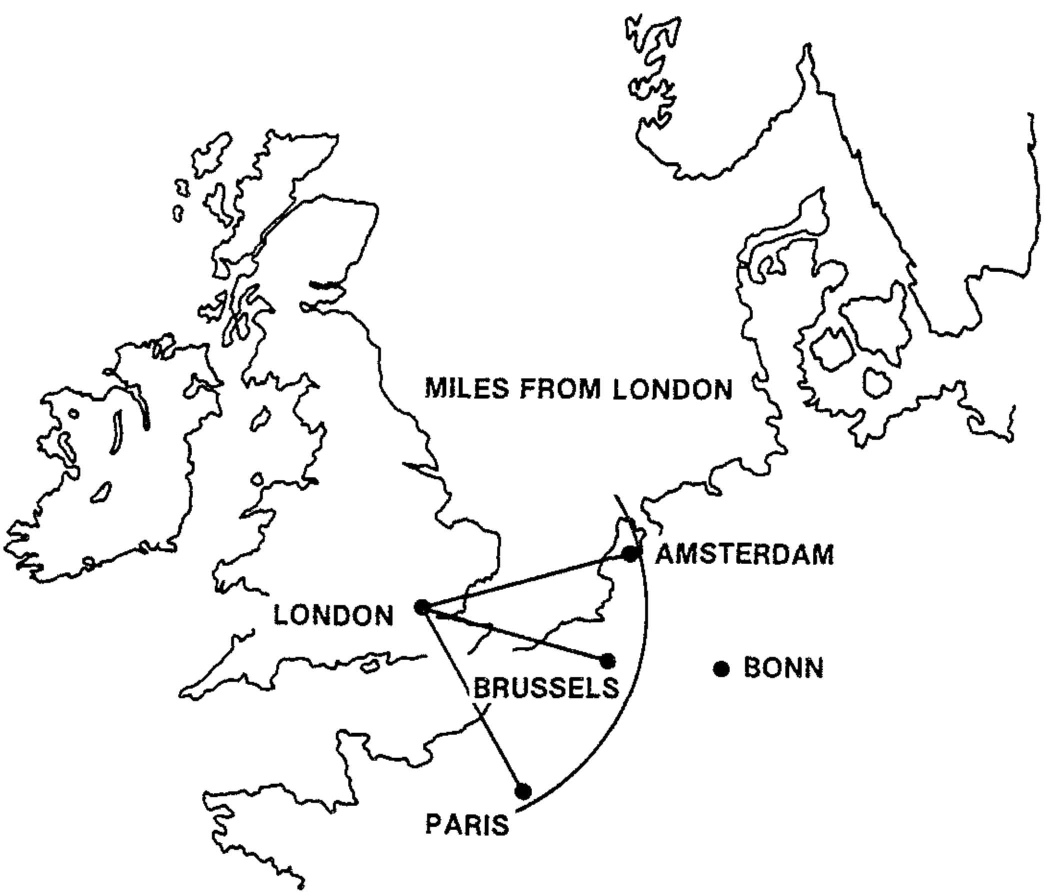

Figure 13. London/Paris/Brussels/Amsterdam Operating Area

TERMINAL AREA OPERATIONS

When considering operation of civil V/STOL aircraft in populated areas the question of noise becomes an important, and sometimes emotional, issue. In May, 1979, the International Civil Aviation Organization (ICAO), Committee on Aircraft Noise adopted a standard for Helicopter noise, and in July, 1979 the FAA published a similar rule as a notice of proposed rule making. As a minimum these regulations will place a ceiling on escalation of noise, and will require the manufacturer to commit research in order to apply the best technology to noise reduction. Aircraft designed to these rules will probably have somewhat higher delivery and direct operating costs. Adherence to the rules, however, will not necessarily ensure complete community satisfaction in all situations. A concerted effort by both manufacturers and users to show the neighborhood councils that the V/STOL operation can have a positive influence on the economy and growth of a region will be required.

Compliance with noise restrictions will require the use of low rotor speeds, thin tips, and advanced airfoils. By careful application of these principles we have been able to develop a new fiberglass rotor for the Model 234 Civil transport and Military Chinook helicopters which permit those large (46,000 to 50,000 pounds) helicopters to comply with the new standards (Figure 14).

Tilt Rotor configurations will be even quieter than helicopters in forward flight, because very low tip speeds can be used due to the relatively large size of the rotor when acting as a propeller. In the hover mode, higher tip speeds must be employed which combined with high disc loading tends to make the Tilt Rotor noisier than the Helicopter. More research is needed in this area.

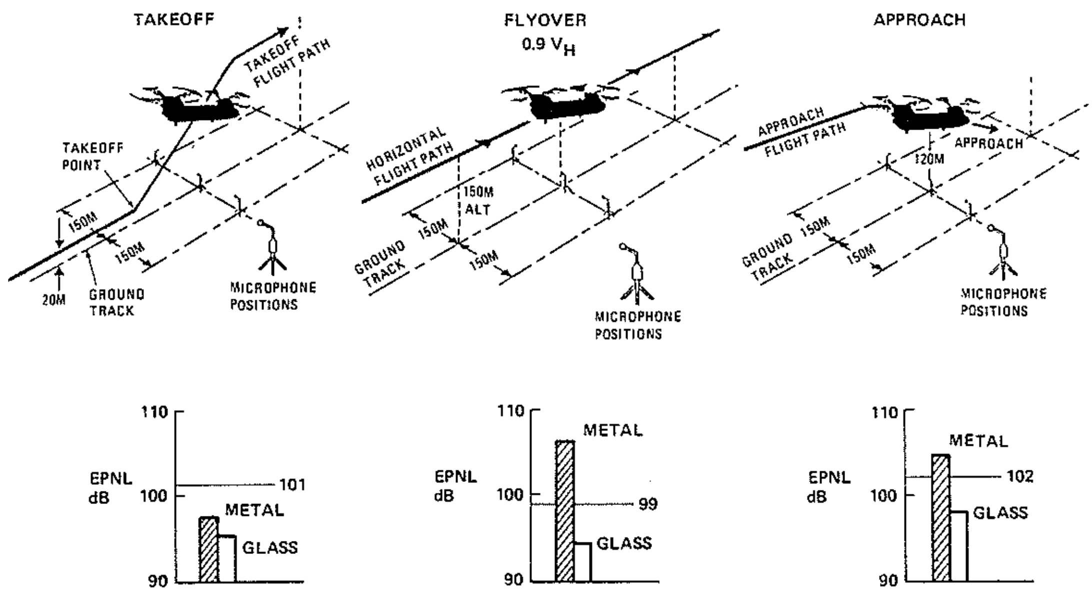

Figure 14. Helicopter Noise Tests

CONCLUSIONS

- By stretching the fuselage 10 feet, commercial aircraft can be derived from the high technology military design HXM/HXS aircraft at a seat mile cost of 40 to 60% of present helicopters, and with a range capability of 400 to 500 miles.

- Advanced technology yields approximately 10 to 20% lower gross weight aircraft and 10 to 20% better operating economies than the normal technology growth by 1985.

- The Compound and the Helicopter have comparable seat mile costs in this study. If both were designed to the same mission range rather than being developed from the military configuration, the Compound's seat mile cost would be 10 to 15% greater than the Helicopters due to higher initial cost and cost of operation.

- The Tilt Rotor and Folding Tilt Rotor have comparable seat mile cost. A decision to proceed with development would be based on risk rather than operating economies.

- Mission fuel of the Compound was approximately 10% greater than the Helicopter and the Tilt Rotor and Folding Tilt Rotor were 10 and 15% less than the Helicopter.

- Only the Helicopter is competitive in the utility logging and construction market.

REFERENCES

1. Peck, W. B. and Schoen, A. H., The Value of Various Technology Advances for Several V/STOL Configurations, Paper Presented at the Fourth European Rotorcraft and Powered Lift Aircraft Forum, Stresa, Italy, 1978.

2. Liiva, J., Clark, R.D., McHugh, F. J., Newnham, A.G., Navy Medium VTOL Design Study, Summary Document and Appendix, Boeing Vertol Document D210-10727-1, 2, Philadelphia, Pa., Feb 1974.

3. Herrick, G. E., and Fleming, R. J., Rotary Wing Concepts for Navy/Marine Corps Medium VTOL Applications, Sikorsky Aircraft Report SER-50856, Sikorsky Aircraft Div, United Aircraft Corporation, Stratford, Connecticut, Jan 1974.

4. Unger, G., Navy/Marine 1980 Rotary Wing Candidate AHS Paper presented at the 31st Annual National AHS Forum, Washington, D.C., 1977.

5. Fry, B. L. and Zabinsky, J. M., Feasibility of V/STOL Concepts for Short-Haul Transport Aircraft, NASA CR-743, May, 1967.

6. Fry, B. L. and de Decker, W. R., A Review of Commercial V/STOL Aircraft and Their Operating Environment, Paper Presented at the National Aerospace El ectronics Conference, Dayton, Ohio, May 1968.

7. Magee, J. P., Clark, R. D., and Giulionetti, D., Rotary-Wing Aircraft Systems for the Short-Haul Market, Paper Presented at The American Institute of Aeronautics and Astronautics, Washington, D.C., 1975.

8. Wiesner, W. and Snyder, W. J., Efficient Civil Helicopters: The Payoff of Directed Research, Paper Presented at the 33rd Annual National AHS Forum, Washington, D.C., 1977.

9. Ellis, C. W., The Most Significant Factor in Today's Helicopter is Operating Economics, Presented at the 35th Annual National American Helicopter AHS Forum, Washington, D.C., May, 1979.

10. FAA, IFR Helicopter Operations in the Northeast Corridor, FAA Advisory Circular AC 73-2, Washington, D.C., June, 1979.