SIXTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 8

ABC^{TM} AIRCRAFT DEVELOPMENT STATUS

D. S. Jenney
Sikorsky Aircraft Division
UNITED TECHNOLOGIES CORPORATION
Stratford Connecticut, USA

September 16 - 19, 1980

Bristol, England

THE UNIVERSITY, BRISTOL, BS8 1 HR, ENGLAND

ABC™ AIRCRAFT DEVELOPMENT STATUS

D. S. Jenney, Sikorsky Aircraft Division
UNITED TECHNOLOGIES CORPORATION

ABSTRACT

Flight testing of the Advancing Blade Concept (ABC) demonstrator aircraft has now reached some significant milestones which invite a look back at what has been learned about this unique concept, and a look ahead at its potential. Instrumented flight testing has reached 238 knots in level flight and load factors of zero to 2.0 at 210 knots. A large body of test information is now in hand. The data show that the concept has no fatal flaws; feasibility has been demonstrated.

The ABC offers special advantages for several VTOL mission requirements that demand high speeds. Its compactness is a benefit to either shipboard or nap-of-earth missions. Its low disc loading is particularly suited to unprepared landing areas, to rescue missions and to missions requiring extensive loiter. Its agility and fine handling qualities at all speeds appear well suited to gunship roles.

Potential applications in three size classes were examined, and they give a promising look at what the future can bring.

1. INTRODUCTION

Flight research on the Advancing Blade Concept employing the XH-59A demonstrator aircraft has been underway for five years now. The basic goal was to establish the feasibility of the concept, and that has been accomplished. References 1 through 5 detailed wind tunnel tests and analysis that preceded the flight tests. References 6 through 10 discussed some of the results as the flight testing progressed.

As the opening of the flight envelope nears completion, it is time to look again at the uses to which the concept is suited. Pursuit of the concept, of course, was motivated from the start by the benefits to be provided by the elimination of retreating blade stall on a rotor. The greater speed, load factor and altitude capability this offers are generally attractive for many missions. After initial looks at the potential, however, (Reference 2) relatively little effort has been spent definitizing these applications until the test results were in. Even paper designs need a good foundation in design criteria based on the cold realism of flight demonstration. In addition, of course, the mission requirements and the capabilities of competing systems have changed extensively since work on ABC began in late 1964.

Now the concept has been quite thoroughly exercised. Although the "optimum" design parameters have certainly not been derived, a large data bank of performance, handling qualities, loads and stress information has been accumulated. This data bank permits generation of preliminary designs with considerable confidence, and with an eye toward the missions of the late 80's and 1990's. Because the demonstrator aircraft performed basically as expected, these designs don't differ drastically from what could have been created ten years ago, but the level of confidence in the validity of projected performance, weight, handling qualities, etc., is dramatically improved.

This paper provides a brief update of the flight test results to date, and a review of the types of missions which most need the ABC's attributes. Specific preliminary designs to meet several such missions are then described.

2. THE ADVANCING BLADE CONCEPT

The ABC idea has been described several times in the literature (References 1, 3 and 10 for example). The concept employs two coaxial counterrotating rigid rotors to eliminate the usual rotor limitations of retreating blade stall. The retreating blade of each rotor is unloaded as required to avoid stall, and the lift is transferred increasingly at higher forward speeds to the advancing blades. Since the advancing blades of the counterrotating rotors oppose each other (Figure 1), the rolling moments produced are in balance. In effect, the center of lift of each rotor is shifted outboard onto the advancing side of the disc - typically by 15 or 20% of the radius. With retreating blade stall effectively eliminated as a rotor limitation, the rotor capability is extended to higher speeds (Figure 2) or altitudes (Figure 3).

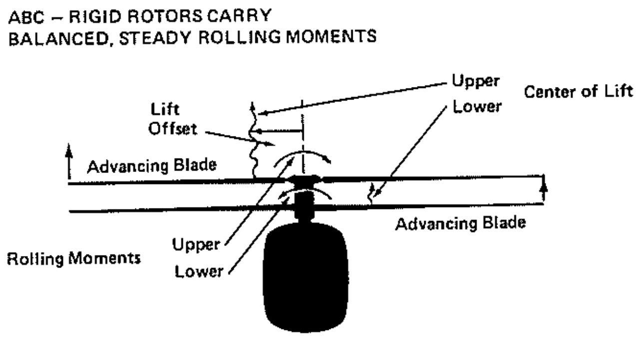

Fig. 1

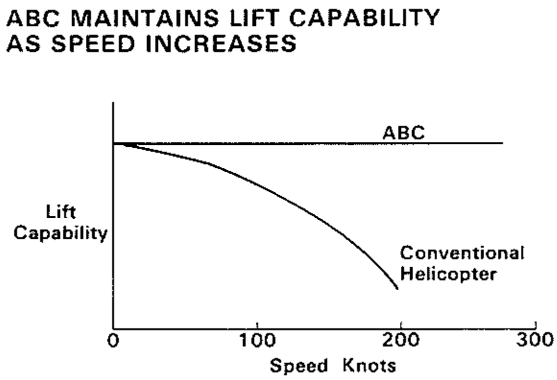

Fig. 2

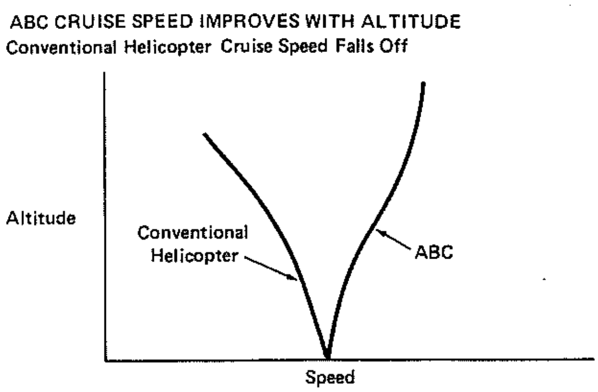

Fig. 3

The differential moments between the two rotors tend to move the blade tips toward each other on the left-hand side, as the aircraft is configured. For this reason, and to keep the required spacing between rotors to a minimum, the rotor blades are rigidly attached to the hubs, and the blades themselves are very stiff. Modern materials - titanium on the demonstrator and graphite/fiberglass/epoxy on future designs - have made it possible to produce such rigid blades with reasonable system weight.

The coaxial rotor arrangement eliminates the need for a tail rotor and thereby eliminates the power demands of the tail rotor while reducing complexity, maintenance burdens and noise. Yaw control at low speed is provided by differential collective pitch to the rotors. Above 80 knots, differential collective is phased out, and conventional rudder surfaces provide yaw control.

So, the concept offered attractive rotor performance, speed and lift capability as primary benefits, with important secondary benefits in simplicity, compactness and low noise as a result of elimination of the tail rotor. There were also some risks, particularly in areas that don't readily lend themselves to analysis. These included the handling qualities of an aircraft with such rigid rotors, the airframe vibration that would result from rotor exciting forces and the weight of the rotor system designed to handle the ABC loading. In addition, of course, there could always be the unknown/unknown problem that becomes only too obvious once real hardware has been exposed to test. Wind tunnel tests and analysis were used as far as possible to develop an understanding of these potential problem areas, but flight test was needed to be sure that one of these areas didn't contain some "fatal flaw" in the concept.

3. XH-59A FLIGHT TEST RESULTS

The XH-59A is shown in flight in the pure helicopter and the auxiliary propulsion configuration in Figures 4 and 5. Figures 6 and 7 list the essential parameters of the two. The only mission of the aircraft is to establish the feasibility of the concept. It was conservatively designed (heavy) and heavily instrumented with no intent to carry payload. At the same time, however, at 9000 - 12,500 lb gross weight, it is large enough to surface problems that might otherwise show up only when scaling up from a small demonstrator to an operational application.

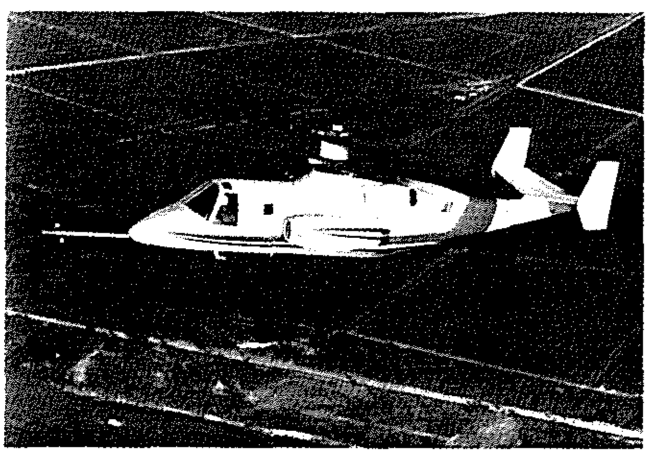

Fig. 4. ABC Pure Helicopter Configuration.

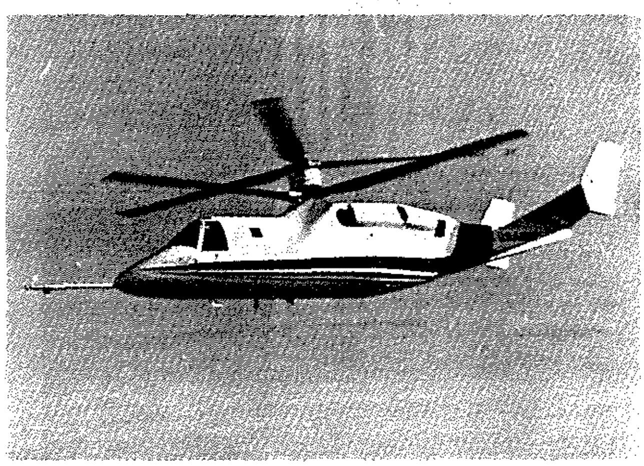

Fig. 5. ABC With Auxiliary Propulsion

ABC HELICOPTER PARAMETERS:

Rotors: Two Coaxial, Rigid Rotors, 36 Ft. Diameter
Blades: Three Blades Per Rotor, Tapered 2/1, Mean Chord 1.44 Ft.
Engine: (1) UACL PT6T-3/T-400, 1800 Shp MIL PWR, SLS
Tip Speed: 650 Fps
Overall Aircraft Length: 41' 5"
Overall Aircraft Height: 12' 11"
Drive System: 1500 Hp
Design Gross Weight: 9,000 Lb
Max. Speed, Level Flight, Sea Level: 160 Kts
Max. Dive Speed: 196 Kts
Des. Limit Load Factor: 2.5 g's
Disc. Loading: 9.0 Psf
Fuel Capacity: 242 Gals

Fig. 6

ABC COMPOUND PARAMETERS:

Same as Helicopter Except -
Engines: (2) J60- 2,900 Lb Thrust, Added
Flight Gross Weight: 12,500 Lb
Max. Speed, Level Flight, Sea Level: 280 Kts
Max. Dive Speed: 345 Kts
Tip Speed Reduced to 450 Fps Above 225 Kts
Des. Limit Load Factor: 1.9 g's
Disc. Loading: 12.5 Psf

Fig. 7

Several papers have been written (References 6 - 10) describing the XH-59A test results. Most characteristics were just about as expected. The discussion here, therefore, will concentrate on the areas of concern prior to the tests and on the few unexpected findings.

3.1 Handling Qualities

The very high control response of the rigid rotors was an early concern. The XH-59A blades are more like propeller blades than helicopter rotor blades, with a first flatwise natural frequency around 1.4 per revolution. Potential problems of control sensitivity were explored before flight, therefore, on a moving base simulator, Figure 8. A simple stability augmentation system (SAS) was provided, with 10% total authority and gains adjustable in flight. Then hovering flight tests began with reduced control ranges, and therefore, reduced sensitivity, and the ranges were progressively opened up to the required values in successive short, hovering flights while the pilots adjusted the SAS gains as desired. Figure 9 shows the progression of control power and damping through that series of flights. The process was very quick since the anticipated sensitivity "problem" never developed. The final SAS gains selected were very close to the values chosen by moving-base simulation - a reassuring result.

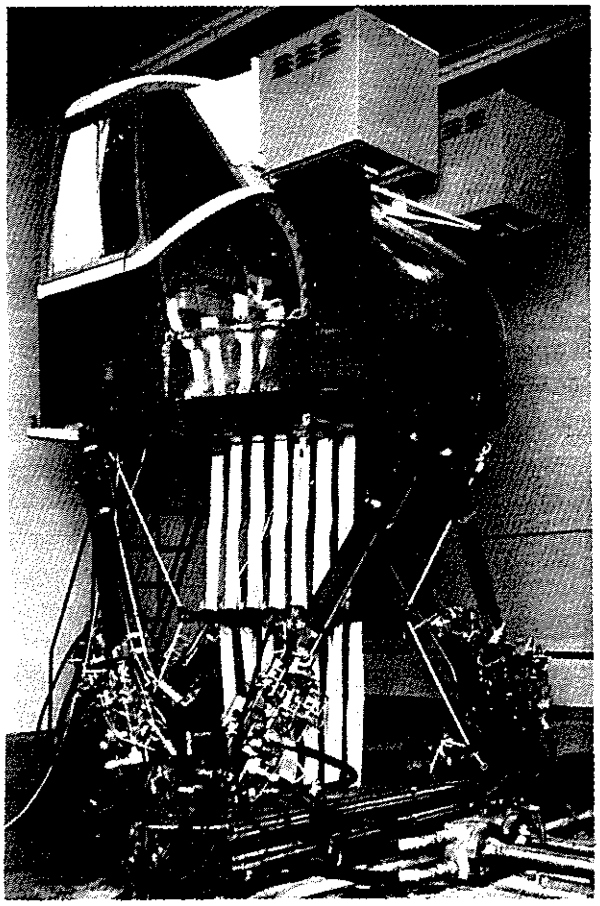

Fig. 8. Moving Base Simulator.

OPTIMIZATION OF LONGITUDINAL CONTROL

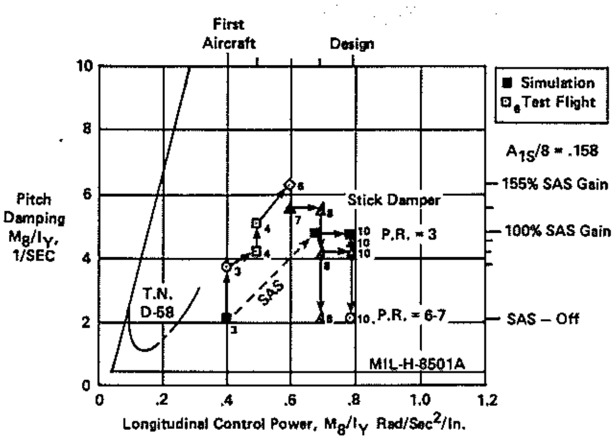

Fig. 9

Since that first build-up, seven other pilots have flown the aircraft without the benefit of any sensitivity build-up, and most have flown with SAS turned off part of the time. The sensitivity just isn't a problem. Another way of looking at control power/damping, in Figure 10, suggests why the XH-59A draws praise from pilots for its responsiveness, rather than concern for its sensitivity. The high damping provided by the stiff rotors makes the asymptotic rates in pitch and roll (roll shown) similar to those of articulated rotor helicopters while it substantially shortens the time required to reach those rates. In effect, then, the ABC rotor provides more nearly a rate-command response rather than acceleration commands. This both highly responsive (agile is the term usually offered) and easier to fly. This agility, which extends throughout the flight envelope, is evident as you watch the aircraft fly, and it is consistently praised by all pilots.

SHORT TIME CONSTANT MAKES ABC EASIER TO FLY

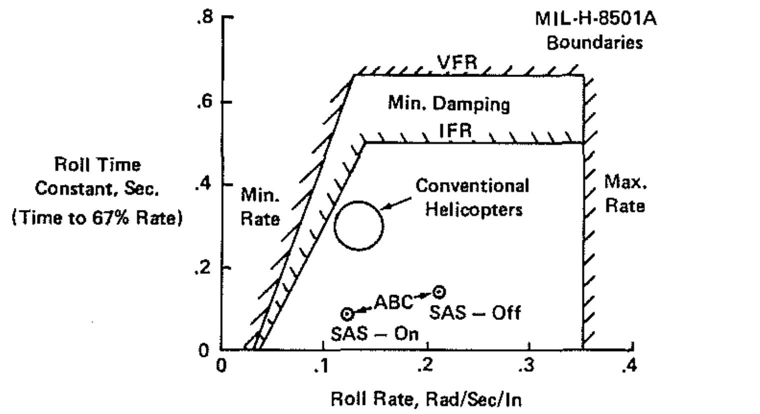

Fig. 10

There are many dimensions to "agility" and ABC excells in all of them. Load factor capability independent of speed has been confirmed (Figure 11). The limits in flight test have been defined by the airframe or transmission design, not the rotor. Clearly, a 0 to 2 g capability at 200 knots is unlike any other helicopter. Figure 12 shows the rates of climb and descent reached so far in the XH-59A. With adequate power installed for 250 knots, the aircraft acquires, at lower speeds, an impressive climb or acceleration capability. This is a "finge" benefit of high speed capability that is even more applicable on a production design than on the XH-59A. The installed power for 250 knot cruise results automatically in sizeable power margins at low speed. Agility, then, can be freedom from stall, high control response, or large reserve power, and ABC has all three.

DEMONSTRATED LOAD FACTOR ENVELOPE

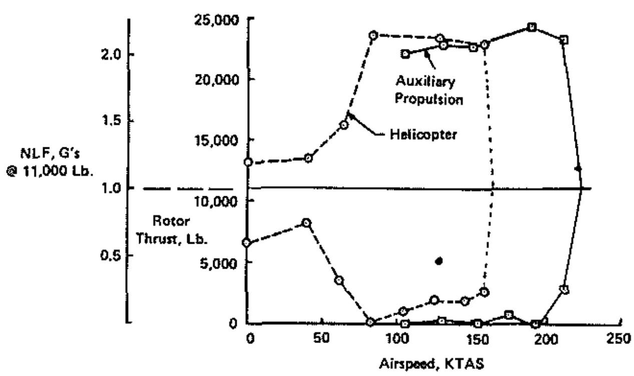

Fig. 11

DEMONSTRATED CLIMB/DESCENT ENVELOPE

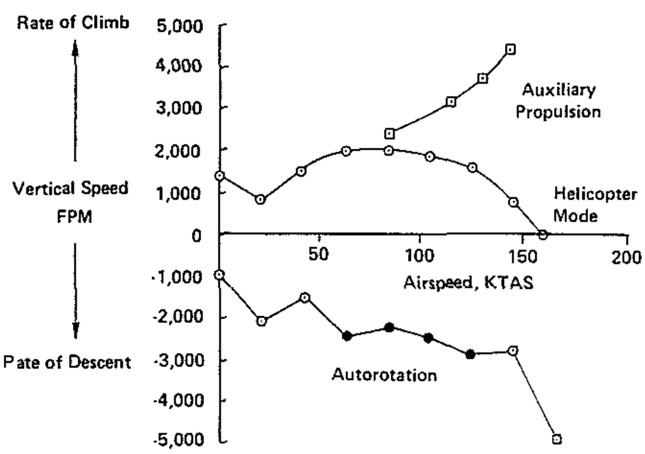

Fig. 12

One adverse surprise in handling qualities was encountered with the XH-59A when it was first hovered with the cockpit doors installed. First flights were made without doors because it was hot (July) and the emergency jettison feature in the doors wasn't working right. When the aircraft first hovered in ground effect with the doors on, the pilots were startled by sudden lateral accelerations by the aircraft without pilot inputs. A repeat flight was made immediately with doors removed and the problem went away. A few flights with tufts and spoilers soon showed that the problem was due to unsteady side forces generated on the fuselage in the downwash of the rotor. The cylindrical XH-59A body does not provide a constant separation point for the airflow - somewhat like the case of a Karman vortex street (Figure 13). The phenomenon is apparently a function of the cylindrical fuselage, not the ABC rotor. Spoilers were reasonably effective, but not desired in high speed flight, so the behavior was accepted as one to be "lived with" for the demonstrator program. For a production aircraft, it is well to remember that a perfectly cylindrical fuselage should be avoided on rotary wing aircraft.

The balance of the handling qualities results have been favorable. Pilots like the uncoupled pitch, roll and yaw response. SAS hardovers and engine cuts are very mild. Autorotational landings have been simulated away from the ground, at a disc loading of about 10.5 psf, with a "roll on" speed of 40 knots. All maneuvers have been repeated, SAS on and off.

ROTOR DOWN WASH/AIRFRAME INTERACTIONS

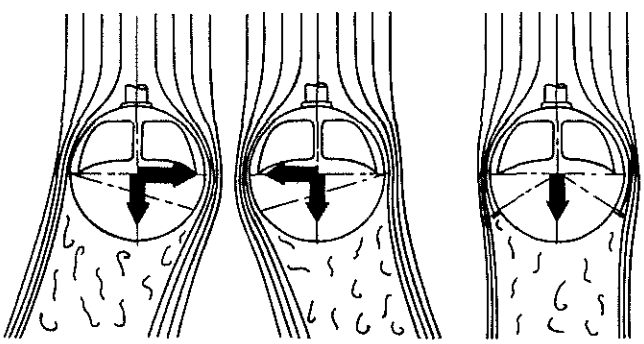

Fig. 13

3.2 Vibration

The ABC rotor, as a hingless rotor of very high stiffness, has the potential for introducing large vibratory moments into the rotor hub. Each three-bladed rotor on the XH-59A will produce primarily 3-per-rev. forces and moments as seen in the airframe coordinates. These excitations are dominated by flapwise moments that are produced in the rotating blade coordinates by 2 and 4-per-rev. vertical bending of the blades.

To the extent that the two rotors are equally loaded, the vibratory moments produced by the two rotors will partially cancel each other out. Figure 14 illustrates that the azimuth angle at which the upper and lower rotor blades cross over each other determines whether lateral or longitudinal forces and moments will cancel. The XH-59A has now been flown with the rotors indexed at both the crossover angles shown in the figure. A change is made simply by opening the gearbox to disengage the rotor drives and re-engage with the rotors repositioned relative to each other.

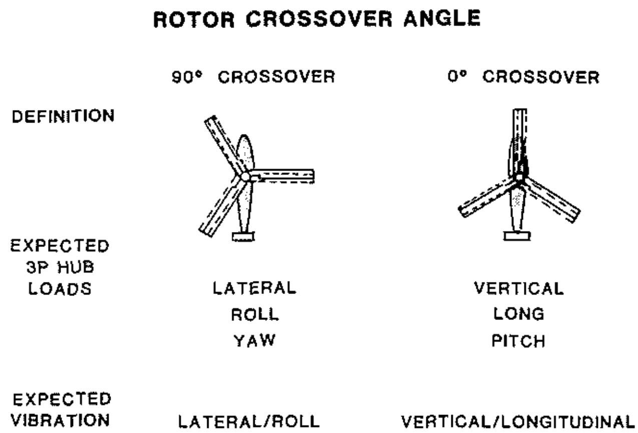

Fig. 14.

In flight tests to date, very little has been done to isolate, absorb or otherwise treat aircraft vibration. The emphasis has been on measuring vibratory loads and how these loads vary with rotor operating conditions. First, measurement of blade root/ vibratory moments showed that, in fact, the expected cancellation between rotors does occur. Figure 15 shows hub 3-per-rev rolling and pitching moments for a 200 knot flight condition. The values shown are determined by measuring blade root bending moments and combining the inputs from the two rotors assuming each of the two crossover angles. Since vibratory moments on the two rotors are nearly equal, rolling moments are reduced by 80% by use of 0° crossover, while pitching moments are reduced by 85% by use of 90° crossover.

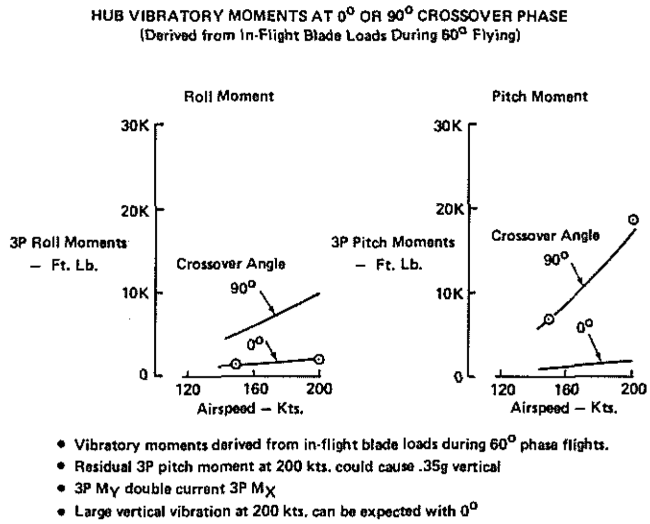

Fig. 15

The XH-59A was built to accomodate a passive transmission isolation system in the roll degree of freedom for use with the 90° crossover angle. The system was built, and may fly later this year; however, at this point, the 0° crossover produces the better cockpit ride, so testing is proceeding in that configuration. Figure 16 shows the crew station g's at 200 knots. The relative strengths of pitch and roll vibration for the two crossover angles were just as expected.

Without vibration treatment, neither configuration gives a ride that is at all suitable for production, but the levels, even at 200 knots, are not too different from untreated helicopters of conventional design at much lower speeds. At 17 Hz, this gave an acceptable cockpit for test purposes.

COCKPIT 3P VIBRATION AT 200 KNOTS

	0° Crossover	90° Crossover
Vertical Gs	0.3	0.3
Longitudinal	0.6	Negl.
Lateral	0.1	0.9
Roll (Pilot's seats)	0.15	0.55

Fig. 16

Rotor isolation is one approach to a production solution, although it appears now that more elegant approaches are good candidates. If a production ABC rotor had four blades per rotor rather than three, the vibrations would be cut approximately in half since 3 and 5P loads are much smaller than 2 and 4P. With either number of blades, the ABC rotor looks like an ideal candidate for application of higher harmonic control. The effectiveness of HHC applied to the XH-59A was calculated for both rotor crossover angles. Control inputs at 3P of only about 1^{o} are required to reduce excitations by up to 80% (Figure 17). Currently HHC is being actively investigated on many fronts, and ABC stands to be a beneficiary of this effort.

VIBRATION REDUCTION POTENTIAL OF HIGHER HARMONIC CONTROL

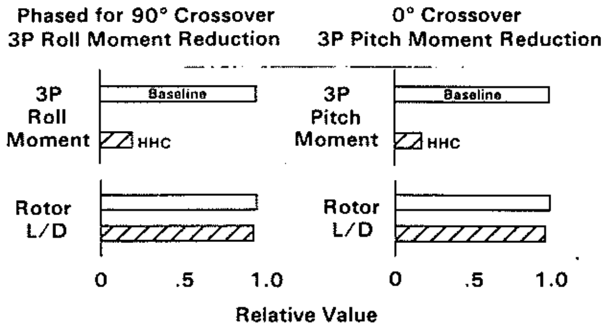

Fig. 17

3.3 Rotor Weight

The final area of concern prior to flight test was the rotor system weight. The XH-59A rotor is heavy, and lighter materials and design concepts are needed to make it weight-efficient. First, however, the flight testing was needed to confirm or correct the design criteria used on the demonstrator. In particular, the flatwise stiffness provided (1.4 P natural frequency) in combination with a rotor spacing of 30 inches for 36 foot rotors (d/D = .07) has a strong influence on rotor weight. This combination is what determines inter-rotor clearance in maneuvers, and only flight test could tell how pilots would actually maneuver the aircraft. In brief, the results have shown the original criteria to be very good. Figures 18 and 19 show tip clearance in pitching and rolling maneuvers. Pullups to 2 g's and roll rates to 50^{o}/sec were reached without reducing the clearance below 12 inches.

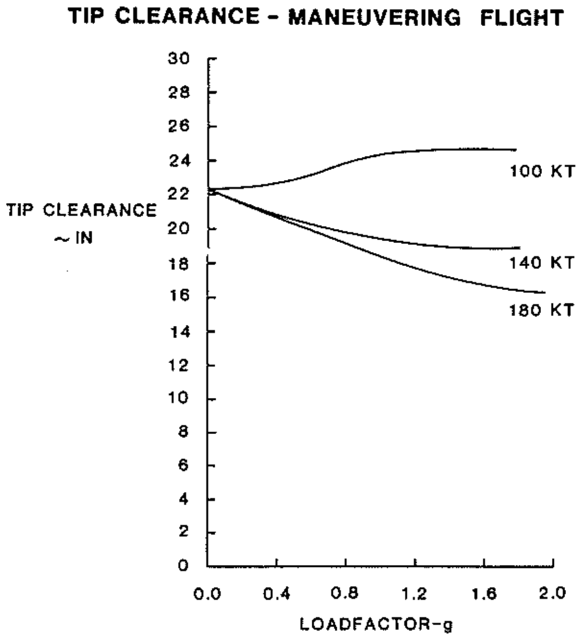

Fig. 18

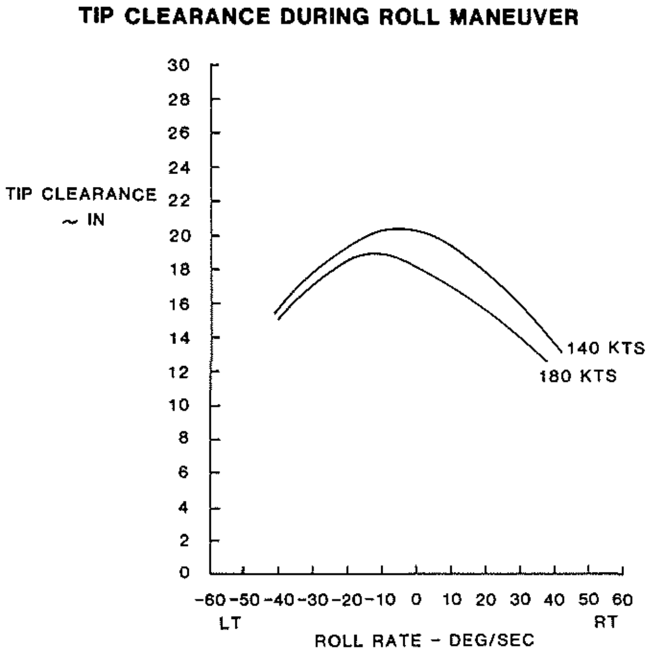

Fig. 19

Applying this criterion, then, to new materials gives some confidence to lighter approaches to the ABC rotor. The present rotor system weighs 1980 lb, 15% of the gross weight. Use of graphite/epoxy in the blade spars for high stiffness, and more efficient hub attachment can reduce this weight by 500 lb, to about 11% of gross weight (see Figure 20). For comparison, articulated rotors are typically 9% of gross weight without including the tail rotor.

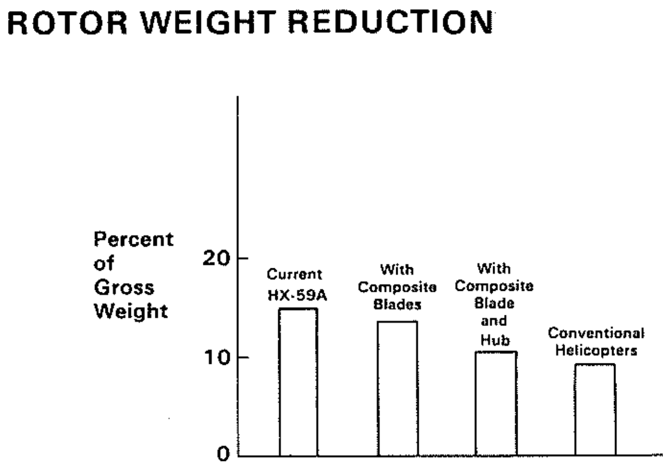

Fig. 20

Several blade retention concepts have been devised that provide this kind of weight saving when compared to the XH-59A rotor. An elastomeric or simple roller pitch bearing with tension-torsion strap provides a much simpler load path and a lighter solution. Alternatively, a completely bearingless solution, scaled up from the Sikorsky/Army BLACK HAWK tail rotor may be possible, and directly integrated with a composite blade spar. Demonstration models of these concepts have been built so far.

4. ABC APPLICATIONS

Currently known missions that an ABC helicopter might perform tend to group into three size classes:

9,000 Lb Class (XH-59A)

. Armed Scout
. Light Attack
. Light Utility
. Executive Transport

18,000 Lb Class

. Army or Marine Attack
. Special Electronics
. Combat Search and Rescue
. Air Taxi; Civil Utility

36,000 Lb Class

. Marine Medium Assault
. Navy ASW, AEW
. Civil Transport

An ABC vehicle brings to any of these missions a unique combination of high speed, low disc loading for good hover efficiency and compactness. An ABC solution will be somewhat heavier than a conventional helicopter, but where high dash speed is needed,the price appears reasonable.

For many designs when sufficient twin engine power is installed for high speed flight at 250 knots or more, the aircraft is able to hover on one engine. This provides a benefit, available in no other vehicle, that is particularly valuable in nap-of-earth flight or operation off small ships or in all weather civil operations. Once the price has been paid in power, fuel and weight to get 100 knots more speed than a conventional helicopter, outstanding OEI performance is provided as an added bonus.

A light helicopter derivative of the XH-59A is shown in Figure 21 tailored to an expected U.S. Army multi-purpose requirement. The Single-pilot aircraft is shown with a shrouded pusher prop for auxiliary propulsion. As a scout or attack aircraft, it could use a periscopic sight above the rotors. The utility version could carry a 2500 lb external load, or several troops internally. With dual pilot, it would be ideally sized as a very fast, compact VTOL executive transport. The aircraft shown have about 3000 horsepower in twin engines for a 230 knot dash capability. At a disc loading of 9 psf, the aircraft can hover on one engine.

ABC LIGHT HELICOPTER FAMILY

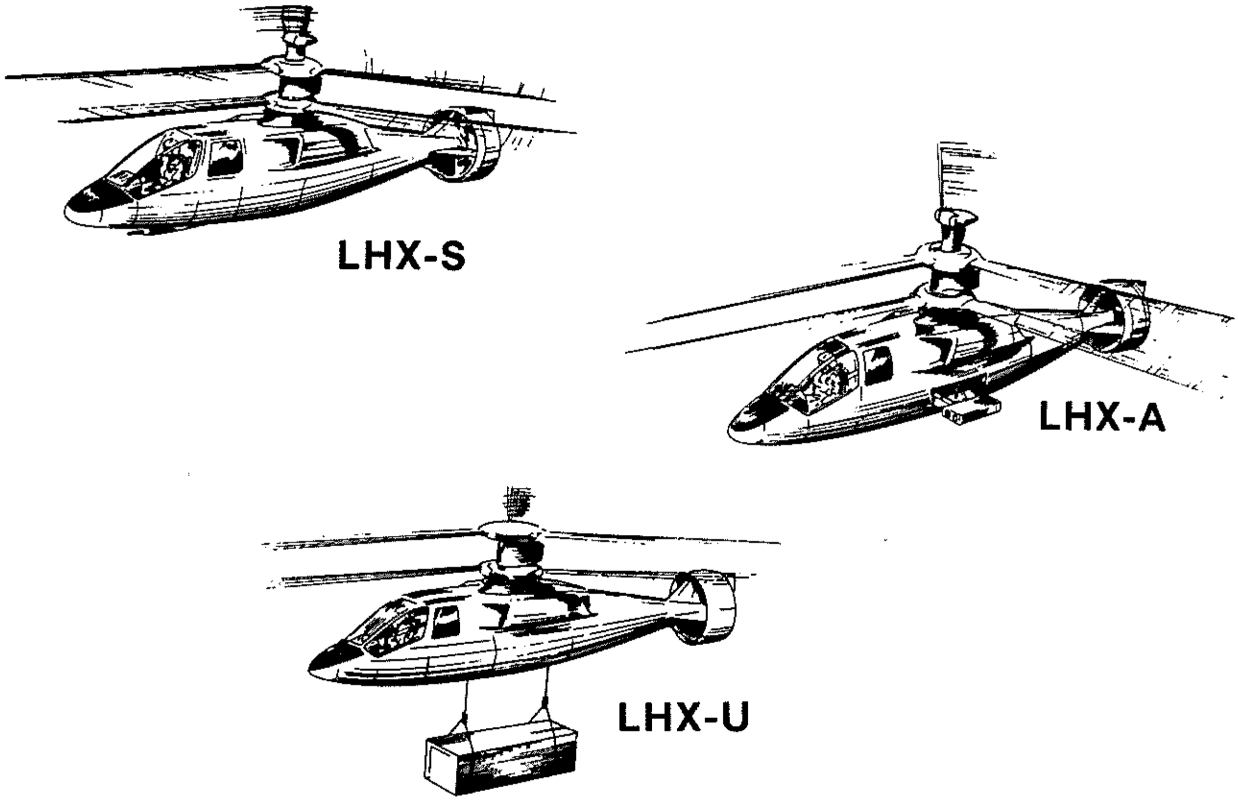

Fig. 21

A number of propulsion system arrangements have been considered for an ABC aircraft. At one time, it was felt that a special convertible fan/shaft turbine engine would be needed for an efficient compound helicopter or ABC. However, development of a special engine for such a special market is unlikely, and such a step isn't necessary. Figure 22 shows the current ABC propulsion concept. Conventional turbo shaft engines drive through the main gearbox to both the rotors and the propulsor. A clutch is provided so that the propulsor (propeller or fan) can be shut down if desired in loiter or on take-off and landing. Dual props. or fan may be used if the mission requires them.

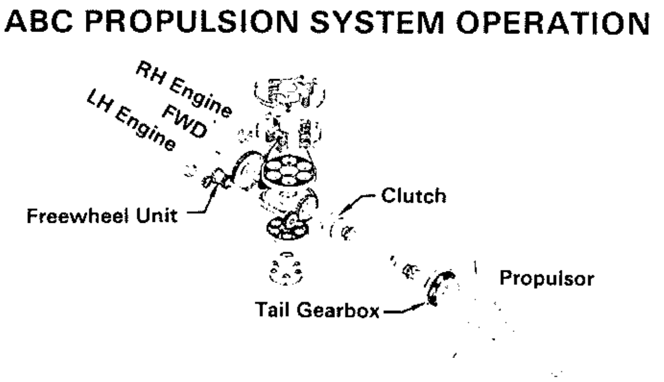

Fig. 22

The second size class for ABC aircraft covers a wide range of potential applications. Figure 23 shows an advanced attack aircraft of 17,000 lb gross weight. This aircraft can carry the mission payload of the AAH, but at a 50% greater speed.

Fig. 23. ABC - Advanced Attack Helicopter.

Figure 24 summarizes the parameters of an AHX based on ABC technology. For this mission, the excess power available at low speed is of double interest. The single engine hover is notable but equally important is the maneuverability due to power available. The aircraft could climb vertically to 300 ft. in six seconds or move forward or to either side by 400 ft. in the same time. The 225 knot dash also provides substantial sustained load factor capability at 175 and 200 knots - characteristics that are probably vital to helicopter air-to-air combat.

ABC FOR AHX

	2000 Ft 70°F	4000 Ft 95°F
Weight Empty, Pounds	10,460	10,460
Mission Avionics and Armament, Pounds	4,400	4,400
Fuel, Pounds	2,170	1,590
Gross Weight, Pounds	17,580	17,000
Disk Loading, PSF	10.3	10.0
Power to Dash, Horsepower	4470	4330
Dash Speed, Knots	220	225
Endurance, Hours	2.5	1.83
Vertical Acceleration from Hover, g's	0.5	0.5
OEI	HOGE	HOGE

Fig. 24

An ABC aircraft the same size could carry out special electronics missions with a time on station of four hours at 17,000 ft. altitude and a 2500 lb avionics load. This mission approximates that now done by the fixed wing Mohawk, and of course, eliminates the need for airfields to support it.

A combat search and rescue aircraft based on the AHX is shown in Figure 25. The disc loading is 10, like that of the HH-53's used for the mission in Viet Nam. The dash speed is 225 knots, for a 250 n.m. radius with a crew of three. Aerial refueling could be used for longer ranges.

Fig. 25. ABC Combat Search and Rescue.

The largest size ABC application currently being studied is a 36,000 lb class tailored to a variety of Navy/Marine missions and suitable as a 30 passenger civil transport. Invariably, when transport missions are discussed, the cruise efficiency of L/D of the ABC is questioned. The drag of two rotor heads, however simple they are, must be reckoned with when productivity is the concern. This is too large a topic to cover in detail here, but some added perspective on the parameters involved is helpful. First, the XH-59A demonstrator drag has turned out to be what was expected - a total equivalent parasite drag area of 16 sq. ft. including auxiliary jet installations and instrumentation. Based on this performance and the benefits expected of fairings over the two rotor heads (3 sq. ft.), the XH-59A should achieve a total system L/D of 5 at 200 knots and 4 at 250 knots at 10,000 ft. and 80% rotor speed. Figure 26 shows the effect of L/D and of weight empty fraction on productivity. With a weight empty fraction of .55 to .6, and an L/D of 4, even at XH-59A size, and ABC is at the knee of the curve. Changes in weight empty fraction have far more effect on productivity than do changes in L/D. Note that at productivity of 120 (knots), an increase of weight empty fraction from .55 to .6 (9%) is equivalent to an L/D increase from 4.3 to 6.8 (58%). At shorter ranges, this trend is even stronger.

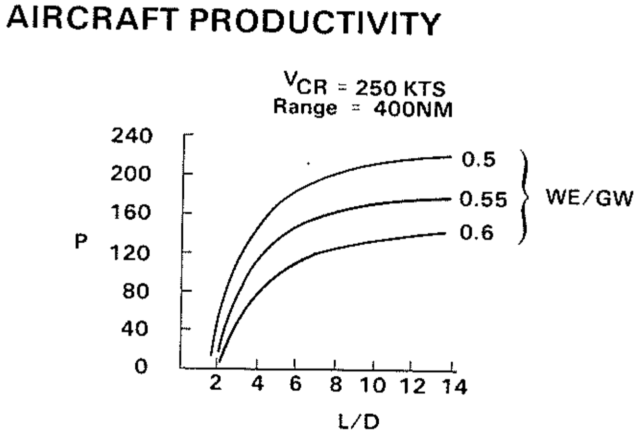

Fig. 26

An ABC design aimed at the U. S. Marine Assault mission, HMX, is shown in Figure 27. The disc loading has been allowed to grow to 15 psf, from 12.5 on the demonstrator. The aircraft is designed to carry 24 troops, a 200 nautical mile radius at 250 knots. Installed power is 7080 hp and the mission gross weight 37,300 lb. The aircraft can hover, one engine out, at mission weight, at sea level, 90^{o}F. Though this aircraft is a bigger extrapolation from the XH-59A (56% in diameter), it provides a nearly unique combination of capabilities - both high dash speed and good low speed performance and flying qualities for support of troops ashore in unprepared areas.

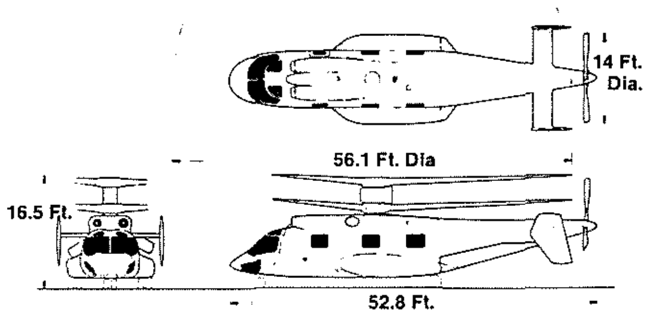

Fig. 27. ABC Medium Assault Transport.

Studies of the Navy Type A multi-purpose V/STOL requirements showed that the dynamic systems of the HXM could also accomplish the HSX anti-submarine mission at a gross weight of 37,000 lb. For this mission, good loiter efficiency and low speed handling qualities for operation off small ships in all weather are special ABC attributes.

The dynamic system for an HXM/HSX aircraft might also become the foundation of a very attractive, 30 passenger civil transport (Figure 28). Designed to carry 30 passengers 500 nautical miles at 250 knots, this aircraft could use either twin props as shown or a single pusher as on the HXM. With propellers shutdown for take-off and landing, the aircraft is very quiet. Customer acceptance should be excellent because of the low noise, good visibility and straightforward flight profiles. Hover on one engine provides an unprecedented level of safety, and its compact size will minimize heliport space requirements. This development probably must wait for the appearance of its military counterpart, but it does provide an enticing glimpse of what the future could bring.

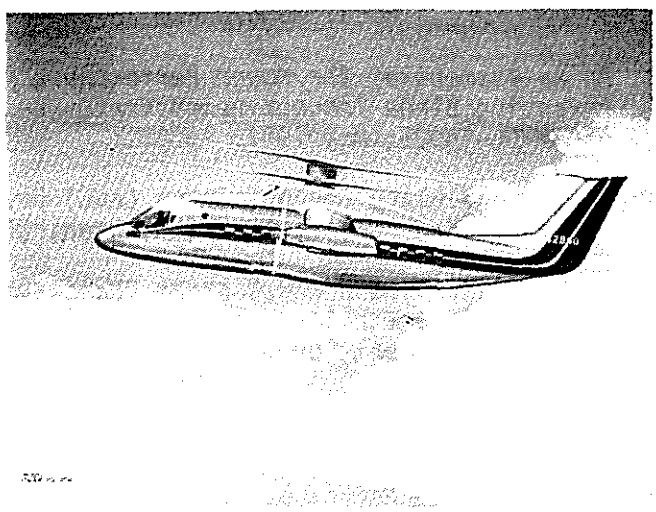

Fig. 28. ABC Civil Transport.

5. CONCLUDING REMARKS

Five years of flight testing the Advancing Blade Concept on the XH-59A have proven the concept's feasibility. The predicted performance, handling qualities and rotor behavior have been confirmed and no significant adverse new concerns have appeared. In fact, several characteristics such as low noise, high control response and mild engine cuts or SAS hardovers have been pleasant surprises. Loads and vibrations have been measured and are manageable, generally confirming the design criteria used on the demonstrator aircraft.

With feasibility demonstrated, it remains for the limits of the system's capability to be defined, and for the system to be optimized in terms of handling qualities, vibrations, performance and loads. Then more weight-efficient structural concepts must be developed for the rotor, propulsion and controls. Each of these steps appears straightforward, and the resultant system designs, as outlined here, certainly make the goal appear worth the effort.

6. REFERENCES

1. M. C. Cheney, Jr., The ABC Helicopter, AIAA Paper No. 69-21, Georgia Tech. February 1969.

2. R. K. Burgess, Development of the ABC Rotor, Paper No. 504, 27th AHS National Forum, Washington, DC, May 1971.

3. V. M. Paglino, Forward Flight Performance of a Coaxial Rigid Rotor Paper No. 524, 27th AHS National Forum, Washington, DC, May 1971.

4. V. M. Paglino, E. A. Beno, Full-Scale Wind Tunnel Investigation of The Advancing Blade Concept Rotor, AMRDL Technical Report 71-25, August 1971.

5. A. E. Phelps, R. E. Mineck, Aerodynamic Characteristics of a Counter-rotating, Coaxial Hingeless Rotor Helicopter Model With Auxiliary Propulsion, NASA Technical Memorandum 78705, May 1978.

6. D. N. Arents, An Assessment of the Hover Performance of the XH-59A Advancing Blade Concept Demonstrator Helicopter, USAAMRDL-TN-25, May 1971.

7. A. J. Ruddell, Advancing Blade Concept (ABC) Development, Paper No. 1012, 32nd AHS National Forum, Washington, DC, May 1976.

8. R. F. Klingloff, Stability and Control Characteristics of the XH-59A (ABC) Demonstrator Helicopter, Paper No. 1045, 32nd AHS National Forum, Washington, DC, May 1976

References

9. J. T. Abbe, R. H. Blackwell, Advancing Blade Concept (ABC)TM Dynamics, Paper No. 77.33-31, 33rd AHS National Forum, Washington, DC, May 1977.

10. A. J. Ruddell, J. A. Macrino, Advancing Blade Concept (ABC)TM High Speed Development, Paper No. 80-57, 36th AHS National Forum, Washington, DC, May 1980