ONE THOUSAND YEARS OF ROTATING WINGS

by

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ABSTRACT

About one thousand years ago, man invented the first rotating wing device to make use of energy available in the wind. Around four hundred years ago, improvements such as blade twist and new airfoils were slowly introduced by a trial and error process. The first scientific tests took place during the 18th Century.

The use of rotating wings for lifting is the result of developments in our time and are illustrated in this paper by the pioneering efforts of the Dutch rotary wing engineer von Baumhauer.

The paper concludes by giving the author's views on rotary wing aircraft of the present and future. Advances realized in new generation helicopters are highlighted as well as the prospects for the tilt rotor concept now under development.

1. INTRODUCTION

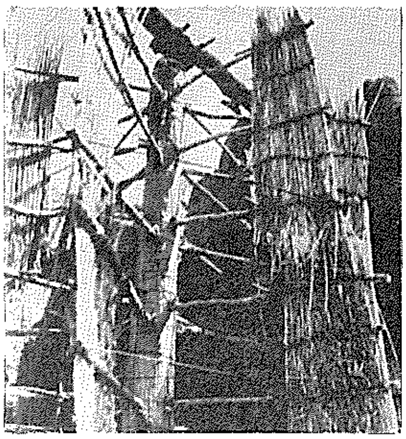
As difficult as it is to get nations of the world to agree on any matter, it is very gratifying to see that differences do not prevent the helicopter community from all over the world to gather together here for this 5th European Helicopter Forum. Rotary wing technology obviously cannot be contained within borders. Indeed, already suggestions have been made towards a World Federation of Helicopter Associations, in which cooperation between European groups, the American Helicopter Society and others would be formalized. We already see steady progress toward this desirable goal.

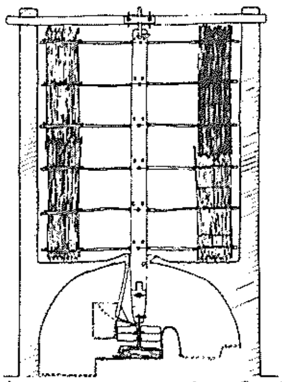
It is my plan in this talk about rotor development to cross national borders and time boundaries. I can do this from a very personal point of view, since my work concerns the future of rotors, while one of my hobbies involves historical studies. Because I also spent half of my working years in Europe and the other half in America, I may be able to convey the international flavor that the subject of my talk requires.

We will span a timeframe of 1000 years. Of course, we can only take snapshots and make giant steps in time. Surprisingly, that is not unlike the nature of technological development itself. Each major breakthrough is followed by a time of consolidation; only the length of the time intervals between the breakthroughs seems to get shorter, indicating that the pace of technological development is accelerating.

2. ONE THOUSAND YEARS AGO

In the year 944 A.D., a historical and geographical encyclopedia "Munj aldahad wa ma'adize al-juwahir" of Abu-l-Hassan 'Ali ibn al-Housain ibn 'Ali al-Masudi was published in Persia which contained the first description of a rotating wing device. It was, in all probability, a vertical axis windmill which was used to drive a millstone for grinding wheat without requiring a gear mechanism.



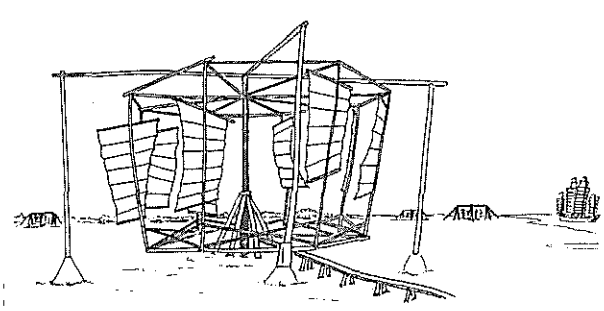


AN ANCIENT VERTICAL AXIS WINDMILL IN AFGHANISTAN

Today in Iran, north of the Seistan Desert and in Western Afghanistan, descendants of these mills are still working in an environment of 120 mph winds, 120 days a year. The aerodynamic principle is very primitive and based on obtaining its driving power from <u>drag</u> forces on a flat plate much like a paddle wheel. Slots in the surrounding building guide the air to one side of the paddle wheel. Fortunately, the strong winds are predominately northerly in that part of the world since the buildings cannot be adjusted for wind directions. The materials of which these ancient rotating wings were made were bundles of reed or papyrus.

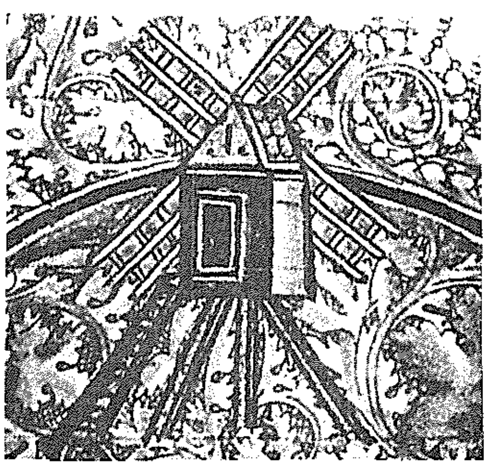
In all likelihood, the idea of the vertical windmill spread to China, possibly during the time the armies of Genghis Kahn (1162-1227) conquered much of the middle East and part of Europe. Improvements were made which eliminated the need for a slotted building around the mill. Today, this principle is still actively pursued in the Darrieus type vertical axis wind turbine, as will be shown later.

Presented at the 5th European Rotorcraft and Powered Lift Aircraft Forum, September 1979

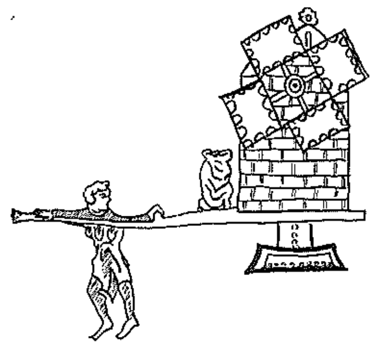


CHINESE VERSION OF THE
VERTICAL AXIS WINDMILL

The knowledge of such an important discovery-the use of windpower-must also have spread rapidly to the West, since there soon appeared reports in Western Europe alluding to windmills. The first dependable document is from the year 1180 in which Alexander de Lieville offers a piece of land adjacent to a windmill to the monastery of St. Lanveur de Vicounte in France. There is evidence suggesting that there were windmills well before that date either in England or France but positive proof is lacking. It would be important to know this date more precisely because it is believed that at that time the first horizontal axis windmill was invented with a rotor not unlike the modern rigid four-bladed helicopter rotor! The earliest date that we have pictures is the 13th Century.



THE FIRST PICTURE OF A HORIZONTAL AXIS
ROTOR (1290, THE WINDMILL PSALTER)



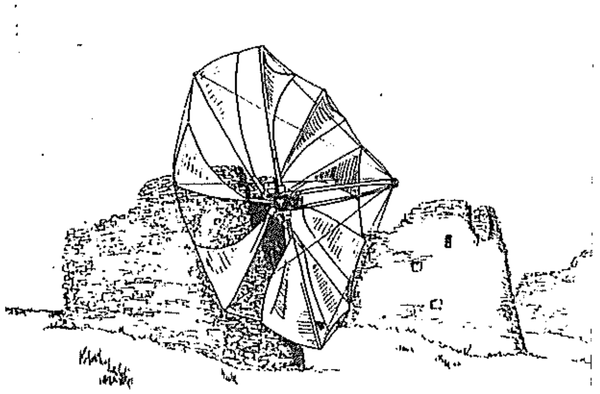
A SECOND 13TH CENTURY PICTURE
(ARISTOTLE'S PHYSICA)

The invention of the horizontal axis windmill rotor signifies a considerable aerodynamic breakthrough because for the first time in a rotating device, the driving torque is obtained by using <u>lift</u> rather than drag forces acting on the rotor blades. (The basic principle applied to linear motions, however, was already known from Egyptian sailboats. The Egyptians found that sails set at an angle permit *boats to travel with a quartering wind.)*

For about three hundred years, little happened in the way of improving the rotor. Windmills became widespread throughout Europe, providing a 5-10 HP powerplant.

The question can be raised whether the Mediterranean windmills with their jib-like sails are in fact not older than the lattice type shown on the 13th Century drawings. The jib-type sails obviously were derived from boat sails developed centuries earlier in Egypt and are still in use on very ancient mills in many of the Mediterranean islands such as Rhodes and Crete. Moreover, the Portuguese poet, Ibne Mucane, suggested in the tenth or eleventh century "If thou art a man of decision, thou needest a mill that will work with the clouds", thus alluding to the notion that there were already windmills in Portugal around the year 1000. And, the mills in Portugal have jib-type sails!

In my studies, I found a 13th Century picture of Constantinople and a 1486 woodcut of the harbor of Rhodes by Brydenback, both of which show lattice type sails. This is surprising since today, the same mills pictured in the woodcut have jib sails. On the other hand, when Leonardo da Vinci reported in 1508 the engineering "know-how" of his time to the Sultan Bayernid II, he made a sketch showing the jib-type rotor construction.



PRIMITIVE FIXED AXIS MILLS WITH JIB-TYPE SAILS AS FOUND ON THE ISLAND OF CRETE

Based on these considerations, I postulate that the Mediterranean sails, in all probability, were invented sometime during the middle of the 15th Century and that the first horizontal axis windmill remains a product of the Western European countries during the Dark Ages. Especially, the Cistercian monks are believed to have been very instrumental in conceiving the first rotating wing device that can be recognized as a forerunner of the helicopter rotor of today.

3. THE GOLDEN AGE

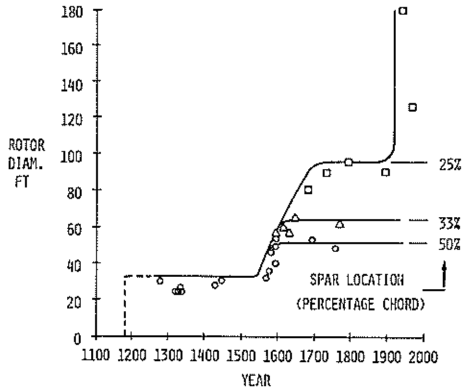
At the dawn of the Dutch Golden Age, which was the time of exploration of the Far East, the time of Brueghel, Rembrandt and of great wealth in the low countries, an important new development took place in the design of rotors. The first step taken was a relocation of the main spar which had been in the middle of the blade up to that time. Evidence of this comes mainly from etchings, engravings and paintings of that time.

BLADE CROSS SECTIONS

BEFORE 1550 THE SPAR WAS LOCATED AT 50% CHORD

AFTER 1650 THE SPAR WAS LOCATED AT 25% CHORD AND FORWARD CAMBER WAS INTRODUCED

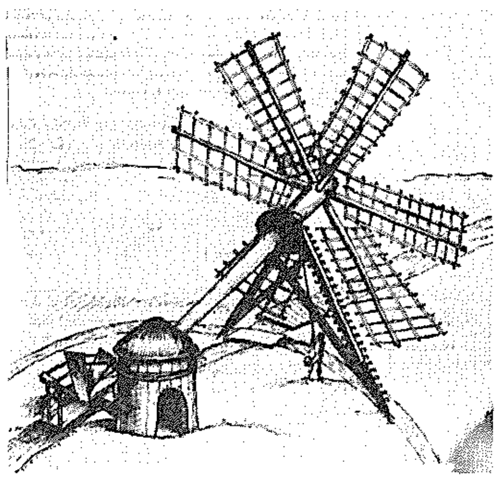
Around 1550, the spar (or blade stock) moved from the middle to the 33 percent blade chord. Then, before 1650, it moved to 25 percent. Modern aerodynamics, unknown to the rotary wing engineers of the 16th Century, teaches that this is the location of the aerodynamic center of an airfoil and that by putting the spar at that point, the airloads will exert minimal twisting moments on the blades. I concluded that this allowed the Dutch in just 100 years to increase the diameter of the rotor from about 30 ft to almost 100 ft, with a corresponding ten-fold power output! Most likely, this technological feat contributed significantly to the development of the country during its Golden Age.



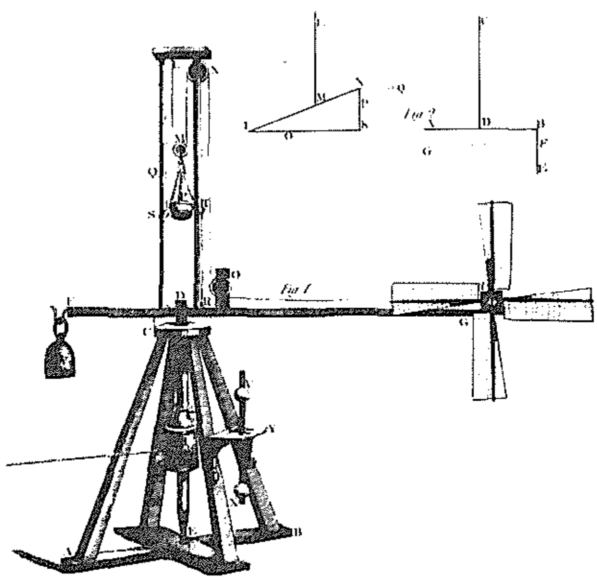
THE INCREASED ROTOR DIAMETER IS ATTRIBUTED TO THE FORWARD MOVEMENT OF THE SPAR

It was not only the location of the spar that was improved, but also the airfoil itself and the twist of the blade. The well-known windmill engineer Leeghwater is said to have invented the wood slat that causes a favorable leading edge camber. Blade twist was introduced shortly after 1600 by an unknown inventor, probably by trial and error. A patent issued to Cornelis Muys on October 31, 1589 (possibly the first patent in the rotary wing field ever issued) is proof of the keen competition among rotary wing engineers of those times. Note from the patent drawing that the spar on that date had already moved to the 33 percent chord position. Unauthorized use of the patent would result in a fine of a hundred gold "realen" and confiscation of all the hardware.

When the Dutch rotor development came to an end in the latter part of the 17th Century, a new center of activity formed in England. The British windmill engineer Smeaton contributed by conducting for the first time scientific tests by using model rotors. The results were published by the Royal Society in 1759.

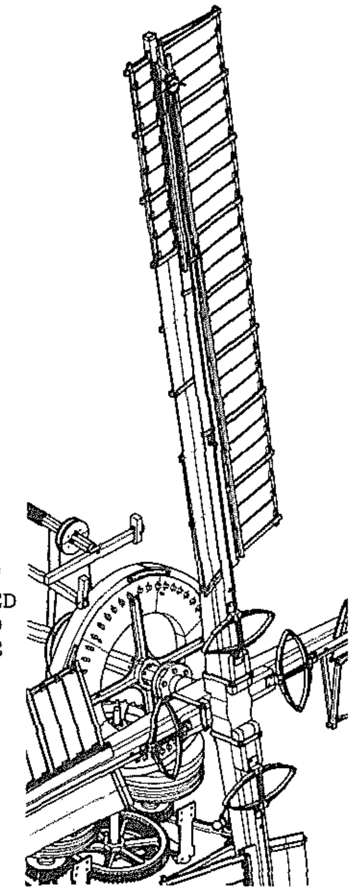


POSSIBLY THE FIRST ROTARY WING PATENT
ISSUED ON OCTOBER 31, 1589

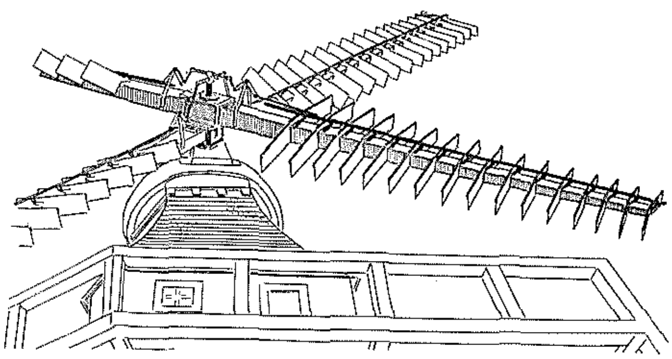


JOHN SMEATON INTRODUCED
TESTING OF MODEL ROTORS
IN 1759

A short time later, the first steps toward automation were taken. In 1772, Andrew Meickle, designed the so-called "spring sail." Leaf springs held shutters in the blades closed until a certain rotational speed was reached. The shutters would then open and prevent overspeeding of the rotor. An improvement was introduced with William Cubitt's patent sails in which the shutters could be controlled by the miller while retaining the automatic overspeed control. A mechanism, not unlike a collective pitch system was used. Many of those rotors are still around in England, Holland, Northern Germany and Denmark.



THE "SPRING SAIL"
AUTOMATIC OVERSPEED
CONTROL INVENTED
IN 1772 BY MEICKLE



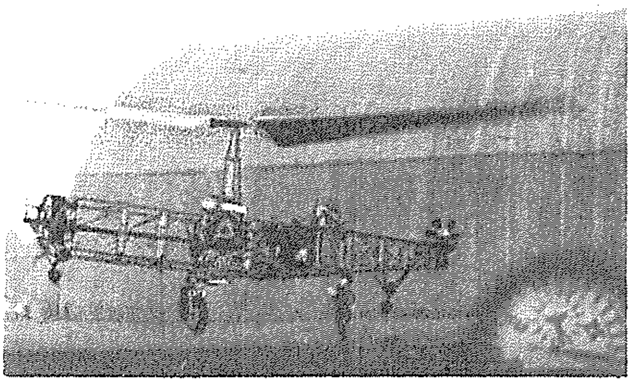
A DANISH VERSION OF THE "PATENT SAILS" OF
CUBITT WITH A PUSH-PULL CONTROL ROD
THROUGH THE SHAFT

Likewise, in France a similar system was developed with longitudinal rather than chordwise shutters. These shutters could be controlled from within the mill, but the action was not automatic.

At the end of the 19th Century, a profound change took place in that aerodynamic analyses were developed which, in our century, led to the design of highly efficient airfoils. This set the stage for the use of rotors for lift rather than for torque. Thus, the era of the rotary wing aircraft started led by Juan de la Cierva.

4. DUTCH CONTRIBUTIONS TO THE BEGINNING OF THE HELICOPTER ERA

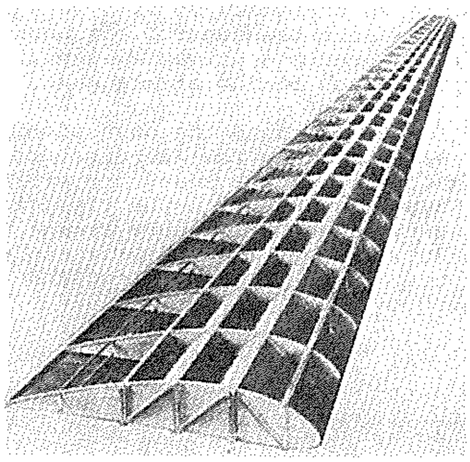
With Juan de la Cierva's autogyro development in 1923, a major breakthrough was accomplished to derive lift instead of torque from a windmilling rotor. The importance of this first step for the development of the helicopter is widely recognized and does not require much discussion before this audience. While it is difficult to assess whether de la Cierva was influenced by Don Quixote to continue his "Never-to-be-imagined Adventure of the Windmills", it is certain that many of the early rotary wing pioneers of this century were actively involved in research of both large windmill rotors and lifting rotors. One of those pioneers was the late Dutch aeronautical engineer von Baumhauer.



THE VON BAUMHAUER HELICOPTER DURING A TEST FLIGHT (FROM THE FILM, ENHANCED FOR CONTRAST)

It is fitting that this 5th European Helicopter Forum pay tribute to von Baumhauer because it is exactly fifty-five years ago in September 1924 that not far from here his helicopter lifted off for a brief moment for the first time. Testing continued until 1930 when the aircraft was heavily damaged due to a fatigue failure in the hub. The difficulties encountered were, in view of present day experience, not unusual. Vibrations, metal fatigue problems, control and stability difficulties are still familiar matters to all rotary wing engineers as many of the papers to be presented at this Forum will testify.

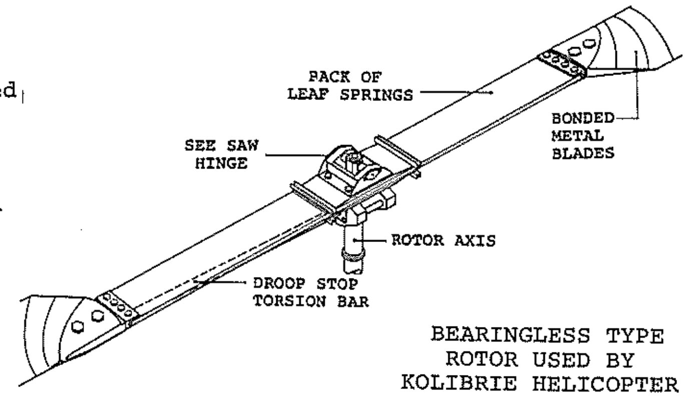
It would be well for us to take a moment and consider some of the technical details: a 15.4m diameter two-bladed rotor with tapered twisted blades (10 degrees), cambered airfoil sections, a solidity of 4.5 percent and cyclic and collective control. In 1912, von Baumhauer was the first to patent and apply such a control system, that also included a swashplate.



TAPERED, TWISTED BLADES WITH CAMBERED AIRFOIL WERE USED BY VON BAUMHAUER

In addition, he patented the tail rotor with a lattice of aerodynamic surfaces in its slipstream for pitch and yaw control, a truly advanced design well ahead of its time.

It took thirty years after von Baumhauer before another Dutch-built helicopter would lift off from Dutch soil, but much had happened in the meantime. Many contemporaries of von Baumhauer, of course, should be mentioned such as Bréguet, Pescara, and Dorand. It was not until 1936 that Focke demonstrated the true capabilities of the helicopter followed in 1939 by Sikorsky's successful VS-300 flights. By then, it became obvious that the helicopter was feasible and practical, but it was not clear what the best configuration would be and what type of power plant should be developed. Many concepts, which even today would be called advanced, were tried out in those early days. Examples can be found in the attempts made to eliminate feathering bearings through the use of torsionally soft but chordwise stiff flexures. The Dutch Kolibrie ramjet helicopter



BEARINGLESS TYPE ROTOR USED BY KOLIBRIE HELICOPTER had such a rotor. Leaf springs attached the blades to the hub. Torsion bars were used to transmit the control motions to the blades through a unique swashplate-collective pitch mixing arrangement.

Those were also the days of experiments with tip jets and the first turbine engines to replace the heavy and vibrating piston-type powerplants. The tip jets have not survived, although a recent news item indicated that the Kolibrie tip ramjet helicopter may go back in production in Israel!

KOLIBRIE RAMJET HELICOPTER SPRAYING IN ISRAEL

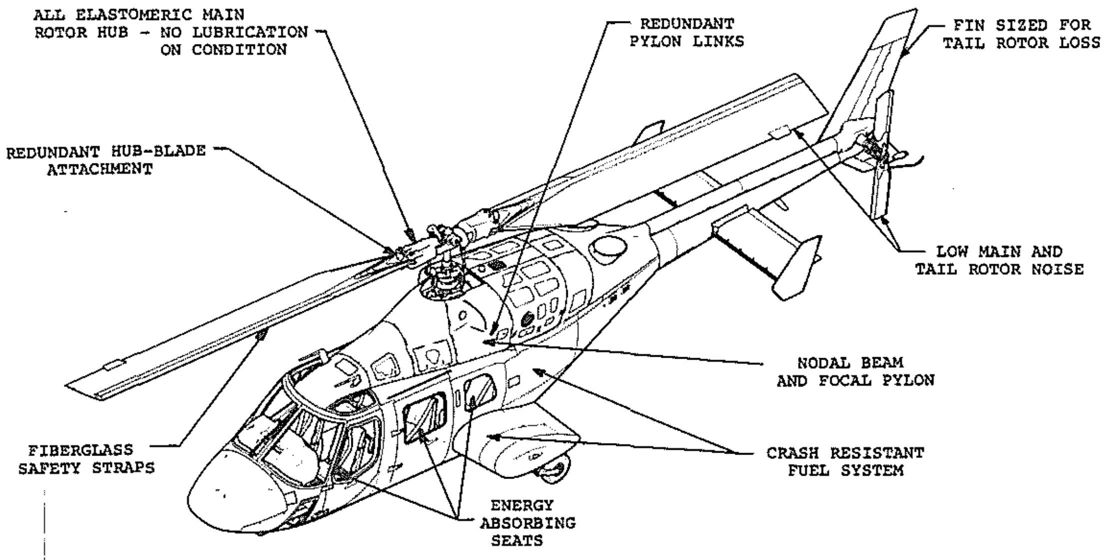
The turbine powered helicopter was the clear winner in the end. The Bell UH-1 Huey and Cobra Series is probably the best example of the success of the first generation turbine helicopters that went into large scale production about twenty years ago.

5. THE NEW GENERATION HELICOPTER

Probably the most significant developments of today are the introduction of new generation helicopters and the emergence of all weather operating capabilities. Concerning the latter, KLM's work in this field is well recognized, showing how airborne weather radar and flight directors can be used to permit IFR flight to and from drill platforms far out in the sea under very adverse weather conditions. The improvements offered by the new generation helicopters are most clearly illustrated by comparing the Bell Model 222 with the Bell UH-1B. Both models, developed about twenty years apart, have about the same gross weight and installed power.

MODEL		UH-1B	222	IMPROVEMENT
YEAR OF INTRODUCTION		1960	1979	
INSTALLED POWER	HP	1055	1170	
GROSS WEIGHT	Lb	7650	7650	
EMPTY WEIGHT	Lb	4523	4650	
V_{ne}	Kn	106	150	42%
CRUISE SPEED @M.C.P.	Kn	122	143	17%
RANGE	nm	204	346	70%
COMFORT				
VIBRATION LEVEL	g	.20	.07	65%
INTERNAL NOISE	dBA	92-97	82-88	-10dBA
EXT. NOISE_HOVER	EPNdB	96	91.5	-4.5dB

We see from the table that very significant improvements in speed, range, comfort and noise have been realized. The reason for the empty weight increase is that weight penalties were accepted in order to improve performance, handling qualities, safety, comfort and noise:



BELL MODEL 222 INCORPORATES MANY SPECIAL FEATURES

- a low tip speed was selected for the main and tail rotor to reduce internal and external noise. Noise insulation through rubber pylon connections and noise blankets reduce the internal noise significantly.
- safety aspects include crash resistant fuel tanks, wings to improve the roll-over characteristic, energy absorbing seats, redundant designs for the transmission mounting and in the rotor hub, and fiberglass safety straps inside the blades providing a fail-safe design. A large fin is designed to give fly home capability in case of a tail rotor failure.
- for vibration reduction, a nodal pylon support is used for 2/rev isolation as well as pendulums in the rotor for reduction of 4/rev vibrations.
- the safety provided by two engines normally calls for higher weight. In the sample case, however, there is no weight increase since engine and transmission technology advanced during the last twenty years to offset this penalty.
- the retractable landing gear is responsible for increasing the speed by 6 knots.
- slotted elevator with endplates provide the basic airframe stability requirements that enable single pilot IFR flight.

The total weight penalty for obtaining all of the desirable goals mentioned above is estimated to be about 400 lb. Interestingly, the weight savings due to new materials, more efficient structural design is estimated to be over 300 lb; hence, only a 100 lb total weight increase is shown in the comparison.

6. THE YEAR 2000

Normally, when we talk about the year 2000, we think of the far and distant future in which anything can happen. Yet, the year 2000 is only twenty years away. Looking back at the accomplishments during the past twenty years may temper our notion of what can be expected. It takes increasingly longer to develop, test, certify and begin producing a new helicopter. The development phase through production of new concepts such as the tilt rotor is even longer. Therefore, one may expect that the results of today's research will take at least twenty years to find their way into production.

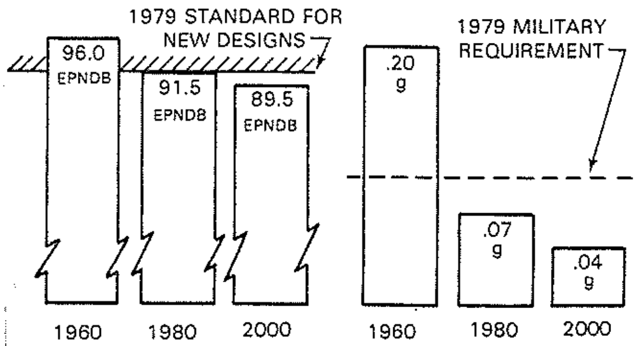
It appears that today we are in the midst of four major development trends that, in the coming years, will have a profound and ever increasing influence on the world of rotating wings:

- the new standards for safety and comfort
- the revolution in materials
- the coming of the electronics age
- the energy crisis

Safety and Comfort

Strong forces are at work today to improve the quality of life. ICAO and FAA are requiring lower noise levels for new helicopters. As a consequence, tip speeds will have to be lower and that will have a detrimental effect on payloads. While the operator community and industry are quite worried about the consequences of this development, it leaves no doubt that the noise levels will be lower in future helicopters. Internal noise levels also will be far lower than in the present helicopters by as much as 3 - 6 dB.

Similarly, vibration levels in the cabin will be drastically reduced throughout the flight spectrum. To achieve low vibrations, new rotors will be tuned to be nodalized at the rotor hub thus eliminating oscillatory shear loads from entering the fuselage. New types of pylons, such as the Bell mercury mount system, are already under development. These advanced systems feature extremely low transmissibility with much lower weight and complexity than the present nodal beam type systems. In addition, much attention will be devoted to eliminate the higher frequencies, which traditionally have been very difficult to predict.



FLYOVER NOISE CABIN VIBRATION LEVELS

8000 LB HELICOPTER

Legal actions concerning product liability are having a profound effect on new designs. The safety features incorporated in new generation helicopters such as the Bell Models 222, 214ST and 412 are already a result of this pressure. It is difficult to predict whether the present trend will continue or stabilize at a reasonable plateau. There is no doubt, however, that fail-safe designs, on-condition maintenance, crashworthiness and improved flying qualities will become standard practice in the next decade.

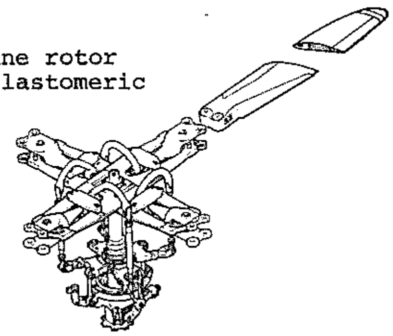
The Revolution in Materials

The introduction of new materials is already in full swing. The use of fiber composites such as fiberglass and graphite for rotor systems is very effective since it provides:

a. high redundancy and benign failure modes.

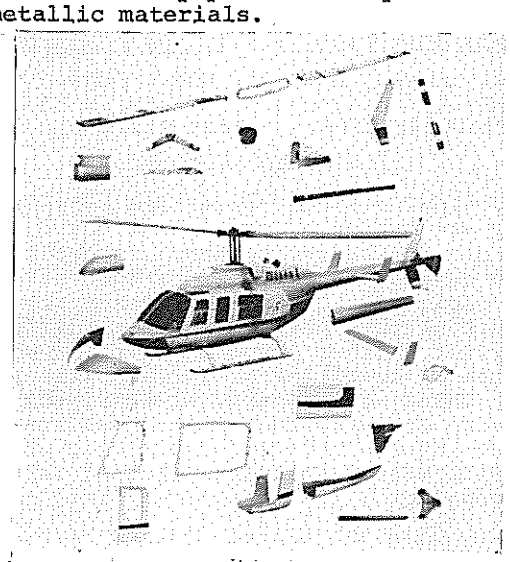
b. the opportunity to make "shaped" blades with optimum airfoils along the span and optimum planform.

Failsafe, infinite-life blades are now possible with improved aerodynamic efficiency (3-6 percent in lifting and speed capability). Automation must be applied in manufacturing for consistency, weight control and cost reduction. While costs in the future will probably be comparable to that of metal blades, little weight saving is expected since rotor inertia and coning angle need to be kept within acceptable limits.



BELL'S 412 FIBERGLASS FOUR BLADED PRODUCTION ROTOR BLADES WITH SHAPED PLANFORM AND VARYING AIRFOIL

Not only the rotor will benefit from composite materials, but also the fuselage. In fact, present production aircraft include many parts already made of non-metallic materials.

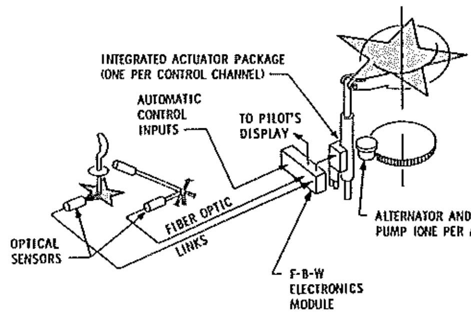


PRODUCTION AND EXPERIMENTAL APPLICATIONS OF COMPOSITE MATERIALS ON THE BELL MODEL 206

In the coming years, we will see the fabrication of an entire fuselage built under the U. S. Army's ACAP Program (Advanced Composite Airframe Program). It is believed that a 20 percent reduction in the construction weight of the fuselage can be realized that would result in a 5 percent empty weight reduction.

The Electronics Age

The electronic revolution is expected to have a profound effect. Multiplexing is certain to come to simplify wiring and to provide significant weight reductions. The power of the microprocessor will be used in many applications such as stabilization, navigation and maintenance monitoring. Digital fly-by-wire and fly-by-light may indeed become accepted ways to control the helicopter. Already, an experimental 206 helicopter has been flying for over a year with a fly-by-light directional SCAS system. The triply redundant STAR swashplate, now operating on a test stand at Bell, may be used with great savings in weight, number of parts and reduced vulnerability, especially for larger rotorcraft. The benefits are even more spectacular for aircraft with complicated control systems like the tilt rotor.



STAR FLY-BY-LIGHT REDUNDANT SWASHPLATE CONTROL (ONE OUT OF FIVE ACTUATORS SHOWN)

Perhaps the electronic revolution will be most noticeable in the cockpit. Human factors engineering, new displays, different controls, and concepts such as touch control will give greatly reduced pilot workload in an uncluttered simple working space.

Perhaps by the year 2000, control of a helicopter can be simplified to the extent that pilot error, which is still the greatest cause of accidents, will be reduced significantly.

The Energy Crisis

The energy crisis affects the rotary wing application and development in many ways. First of all, the helicopter plays a crucial part in the world of oil exploration as KLM Helikopters testifies. With time, we will have to fly faster and farther out to remote drill rigs at sea, and with bigger payloads. These requirements are consistent with another major goal: reduction of fuel consumption and fuel cost of rotary wing aircraft.

There are several aspects to this matter of fuel cost reduction:

a) engine SFC

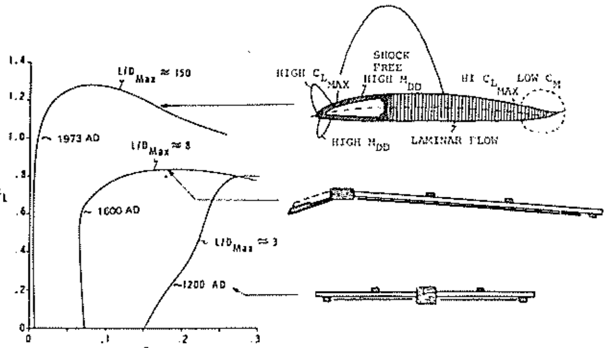
b) hover efficiency

c) forward flight L/D

What can we expect? The advanced technology engines presently under development cannot be improved much more. Higher turbine temperatures and compression ratios are still possible but no more than 5-10 percent improvement can be expected.

What is possible, however, are developments which would permit the operator to shut down one engine during cruise flight. This is not done today because of the danger that the engine cannot be restarted. Yet, the benefits are substantial such as increases of 25 percent in range and 40 percent in endurance. It will require cooperation between the engine and airframe manufacturers and the regulatory authorities to bring about such a development.

Aerodynamic improvements, of course, are important. Transonic airfoil work by NLR here in Holland, Dr. Wittcomb of NASA and many others is now being expanded towards three-dimensional transonic flow. This is of great importance for optimizing tip aerodynamics. Rotor flow based on lifting surface theory is being developed. New blade shapes and improved airfoils are certain to come during the next twenty years. It is expected that these advancements will lead to another 3-4 percent improvement in hover and high speed performance and a reduction of aerodynamic noise of perhaps 6 dB.

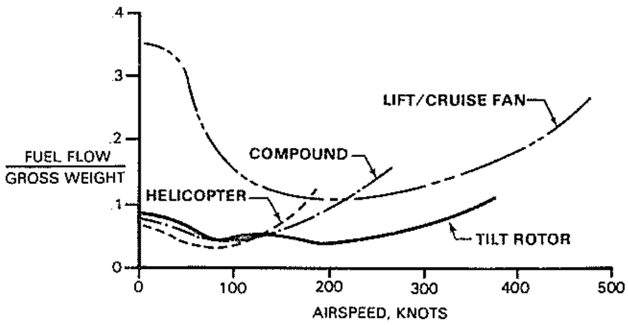


PROGRESS IN AIRFOIL EFFICIENCY
OVER THE AGES

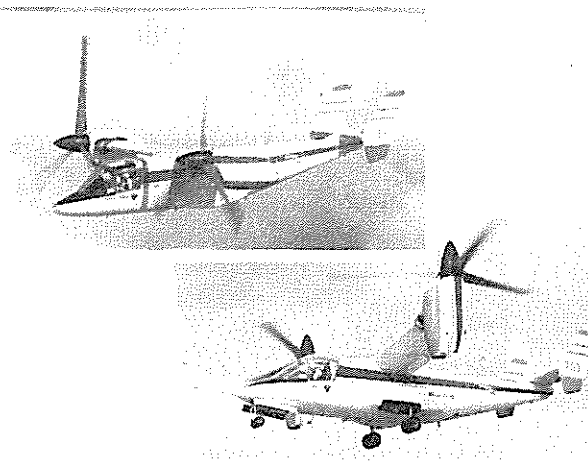
There is no doubt that we still can improve the fuselage aerodynamic shape of the helicopter but the rotor hub and mast will remain a high drag item and the reason that cruise speeds beyond 150-170 knots (depending somewhat on size) will be uneconomical.

Although the compound can fly faster, it still has the same high rotor drag to overcome.

The Bell XV-15 tilt rotor, now in flight test under a NASA-Army-Navy development contract, eliminates the drag penalty due to the rotor and mast by converting the rotor into the wind. The L/D max. value for the tilt rotor is about 10 at a speed of 300 knots versus 4 for a helicopter at 130 knots.

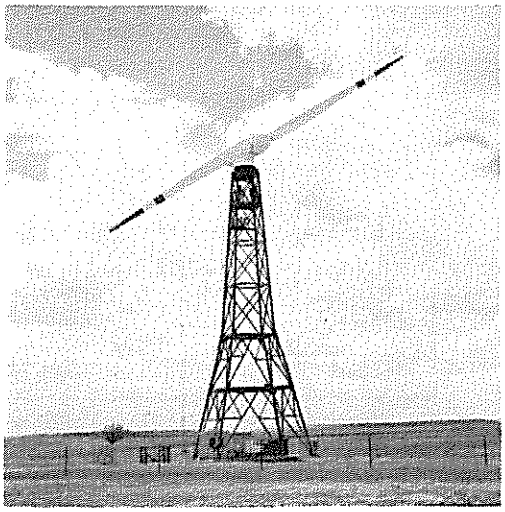


It is expected that the tilt rotor will have reached operational status before the end of this century and that further progress will be made at that time towards the tilt and fold rotor concept, which will permit speeds in the supersonic range. In that instance, the rotor blades are folded back while the pylons are in the converted position. Of course, auxiliary propulsion is then required to propel the aircraft to high speed.

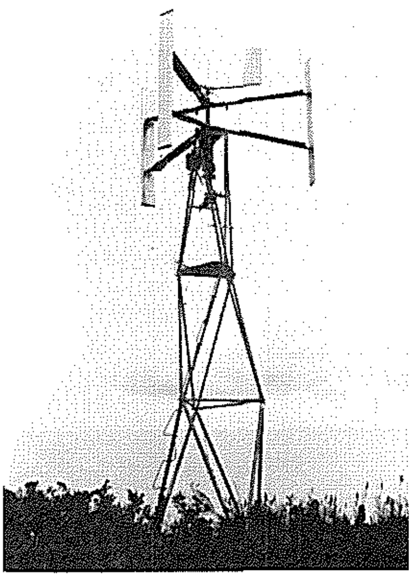


XV-15 TILT ROTOR IN HELICOPTER
AND AIRPLANE MODES

Finally, there is the device that started the rotating wing development and may come back to help reduce the energy crisis - the windmill, or as it is called now, the wind turbine. In Holland, the land of windmills, we need not dwell on its possibilities. As it was a thousand years ago, the horizontal axis and the vertical axis windmills are still being pursued vigorously and it is possible that many of them again will be working with the wind in the year 2000 and beyond.



NASA'S WIND TURBINE IN OPERATION IN NEW MEXICO



A VERTICAL AXIS WIND TURBINE (PINSON ENERGY CORPORATION)

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