

THE ELABORATION OF A NEW FAMILY OF HELICOPTER BLADE PROFILES

J.-J. Thibert

(NASA-TM-75907) THE ELABORATION OF A NEW
FAMILY OF HELICOPTER BLADE PROFILES
(National Aeronautics and Space
Administration) 15 p HC A02/MF A01 CSCL 01C

M81-20031

Unclas
G3/02 41848

Translation of "Définition d'une nouvelle famille de profils pour
pales d'hélicoptères", L'Aéronautique et L'Astronautique,
No. 81, Feb. 1980, pp. 13-19



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JANUARY 1981

STANDARD TITLE PAGE

1. Report No. NASA TM-75907	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle THE ELABORATION OF A NEW FAMILY OF HELICOPTER BLADE PROFILES		5. Report Date January 1981	
		6. Performing Organization Code	
7. Author(s) J.J. Thibert Chief Group Engineer in the Office National d'Etude et de Recherches Aero- spatiale		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, CA. 94063		11. Contract or Grant No. NASW-3199	
		13. Type of Report and Period Covered	
12. Sponsoring Agency Name and Address National Aeronautics and Space Admin- istration, Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes Translation of "Definition d'une famille de profils pour pales d'helicopteres", L'Aeronautique et L'Astronautique, No. 81, Feb. 1980, pp. 13-19 (A80-48126)			
16. Abstract In 1974, ONERA undertook the design of a new airfoil family of rotor blades suited to the specifications of Aerospatiale. Three airfoils with a thickness to chord ratio of 12, 9 and 7% have been designed and tested in a wind tunnel. Their performances, better than those of other airfoils commonly used on helicopters, led Aerospatiale to use these airfoils in a new tapered blade-wind tunnel and inflight tests, confirming the expected gains. This new blade allowed better performances for the Dauphin series and helped the SA 365N to become the fastest machine in its class.			
17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified-Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

The Elaboration of a New Family of Helicopter Blade Profiles

J.-J. Thibert
Chief Group Engineer at the Office National d'Etudes
et de Recherches Aérospatiales [ONERA]

The blade profiles used in the majority of modern operational /13*
helicopters were first elaborated in the 1930's. This basically
stems from the fact that while aerodynamics has always had an important
place in airplane design, the same cannot be said for helicopters.
As a matter of fact, from the end of the Second World War, which marked
the start of the industry, until the end of the 1960's, improvements
in performance were mostly due to mechanical advances, especially
to the use of turbine engines.

In the last decade, meanwhile, major efforts have been made by
all builders to improve the aerodynamics of their machines so as to
better their speed, fuel consumption, and load-carrying characteristics.
As far as the main rotor is concerned, the use of composite materials
has made possible the introduction of tapered blades and also has
allowed helicopter rotors to benefit from the recent progress in
airplane wing profiles.

Within this framework, ONERA, with the support of DRET,
undertook in 1974 the elaboration of helicopter blade profiles that
would meet the specifications established by Aérospatiale. The
ultimate objective was to develop complete blades that performed

*Numbers in the margin indicate pagination in the foreign text.

better than conventional ones.

History of Profiles Used

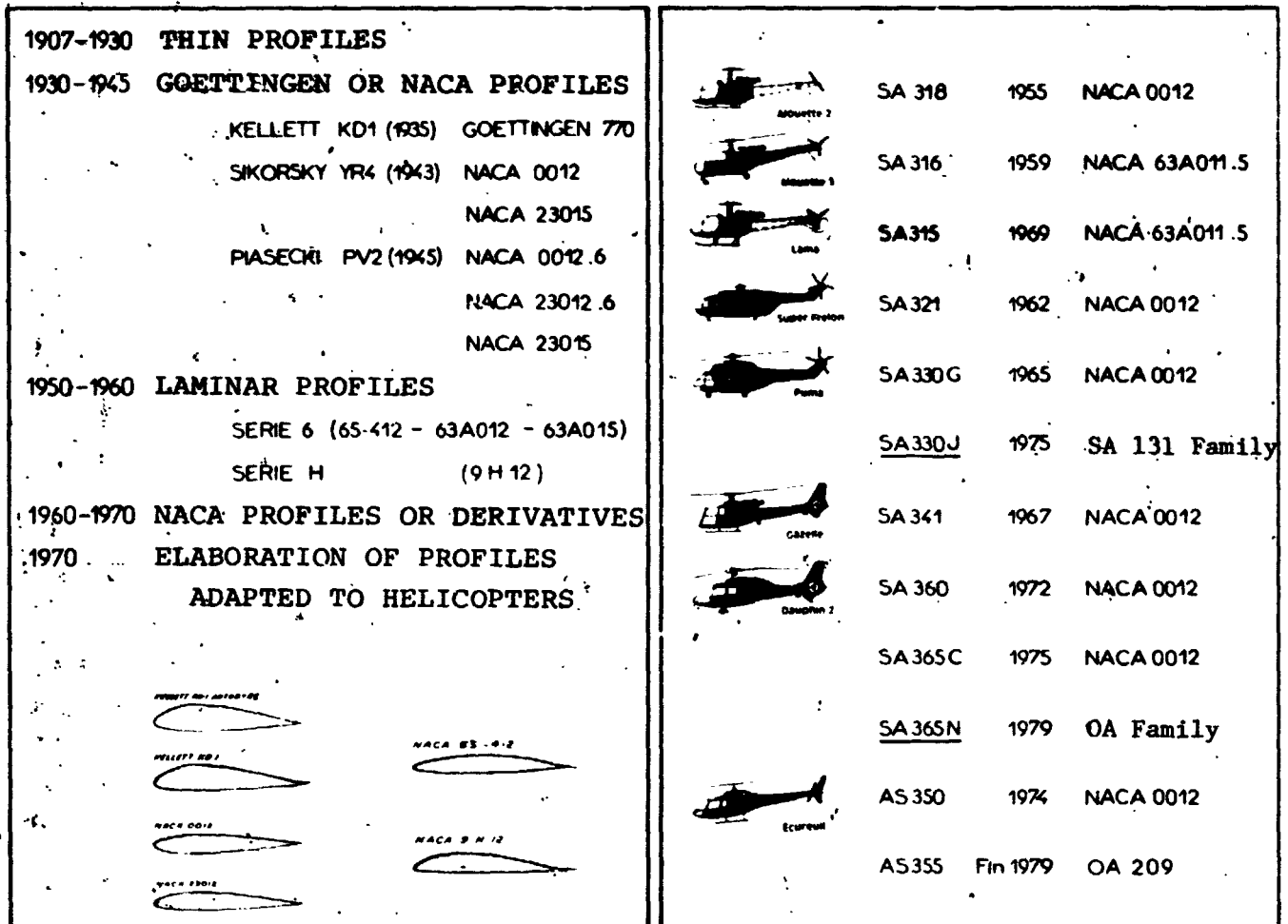


Figure 1
Historical Summary of Helicopter
Blade Profiles

Figure 2
Profiles Used in French
Helicopters

An examination of the profiles used in helicopter blades (figure 1) shows the same evolution took place (with a certain time lag) as in airplanes. Thus, the blades on the first machines had thin profiles. Then, between 1930 and 1945, the profiles came from the famous Gottingen and NACA series (G-770, NACA 0012,

NACA 23012, NACA 23015 ...). During the 1950's, laminar profiles were extended to helicopters with the introduction of the series 6 (NACA 63A012-63A015) and of the laminar series with a low C_{m_0} especially designed for helicopters (9H12). However, the performances obtained were inferior to predictions and in the sixties one witnessed a return to the conventional NACA profiles and their derivatives. It should also be stressed that during this entire period, metal blades had the same profile no matter what their span. /14

Figure 2 shows that the NACA 0012 profile has been widely used on French helicopters. Only recent aircraft such as the SA 330 J version of the "Puma" and the bimotor models of the "Dauphin", the SA 365 N and the SA 366 G, are equipped with tapered blades whose profiles differ from the NACA ones. The AS 355, the biturbine version of the "Ecureuil", was given blades of modern profile, but they have a constant breadth for economic reasons.

Specifications for Helicopter Blade Profiles

The recent evolution toward tapered blades is explained easily by examining the calculated isoMach and isoincidence lines on the rotor disk. A simplified example of these lines is presented in figure 3. The compounding of the speeds of rotation and of advance engenders Mach numbers varying from 0.2 at the root to 0.85 at the blade tip for an advancing blade (azimuth varying from 0° to 180°). On the retreating blade (azimuth varying from 180° to 360°), the Mach numbers are much lower and range from 0.4 at the blade tip to 0, or even negative values (profiles attacked at the following edge)

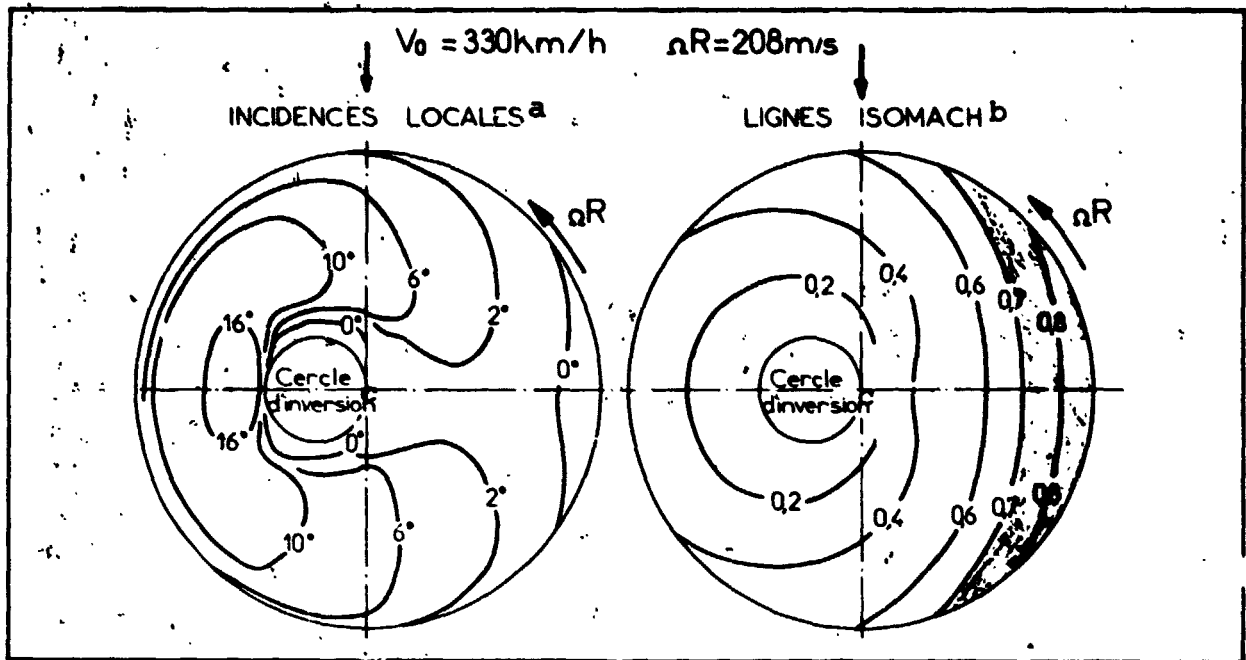


Figure 3
 Example of Calculated Isoincidence and
 IsoMach Lines on a Rotor Disk

- Key: a) Local Incidences
 b) IsoMach Lines
 c) Circle of Inversion

in the circle of inversion near the hub.

Because of this, it is necessary that the amount of lift C_z and, consequently, the angle of incidence be low for the advancing blade and high for the retreating blade to keep the aircraft from rolling.

In the course of a single rotation, the blades therefore alternately undergo low incidences and elevated speeds and then high incidences and moderate speeds. Since the Mach and incidence levels encountered

optimization of rotor performance leads to the use of tapered blades.

The principal spheres in which the profiles function is therefore:

- High Mach-low C_z
- Low Mach-high C_z .

There is a third area to remember when considering an aircraft's stationary flight. The Mach number is then independent of azimuth and, consequently, of C_z , with only a relative variation in speed with radial distance (Mach = 0.6, $C_z \approx 0.6$). Taking account of this analysis of profile operating conditions, a set of specifications for sections at different radial distances can be established in the form of desired performances as a function of the main types of flight:

- Forward flight
- Stationary flight
- Maneuvers

Helicopter blades were divided into three parts based on the increase in Mach number with increasing radial distance:

$$r/R < 0.8, 0.8 < r/R < 0.9, 0.9 < r/R$$

Figure 4 presents the specifications established for each region /16 by Aérospatiale. Emphasis was placed on improving performance in relation to blades with conventional NACA 0012 profiles, in stationary flight by raising the lift/drag ratio at $M_0 = 0.6$ and $C_z = 0.6$ and



Flight Conditions	Preponderant Aerodynamic Coefficient	SECTION 1	SECTION 2	SECTION 3
Forward Flight	M_{dx} at $C_z=0$ \rightarrow	0.80	0.85	0.90
	$ C_{m_0} $ \leftarrow	0.01	0.01	0.01
Stationary Flight	L/D. at $M_0 \sim 0.5-0.6$ $C_z = 0.6$ \rightarrow	75	80	85
Maneuvers	$M_0 = 0.3$ \rightarrow	1.5	1.4	
	C_z max $M_0 = 0.4$ \rightarrow		1.3	1.0
	$M_0 = 0.5$ \rightarrow	1.3		
Added Constraint	e/c \sim	12%	9%	7%

Figure 4
Specifications for Helicopter Blades

and in forward flight by increasing the drag divergence Mach number M_{dx} , but also C_z max in order to avoid retreating blade stall.

It should be noted that the performance requested is clearly superior to that of NACA 0012. For example, the M_{dx} of this profile at $C_z = 0$ is 0.79 and its C_z max at $M_0 = 0.4$ is 1. An extremely severe constraint is also imposed on the pitching moment coefficient at zero lift, C_{m_0} , which has to remain very low so as to limit the stress on the cyclic-pitch control rods.

The various conditions imposed on performance leads one to choose a thick profile for the inner blade region (elevated C_z max) and thin profile for the tip (elevated drag divergence Mach number).

Profile Elaboration Method

ONERA undertook the elaboration of profiles corresponding to the set of specifications. It started with section 2, situated at a distance equal to about 85% of the total blade length and for which the relative thickness should be 9%. The resulting profile, named OA 209, has already been presented in a preceding article (no. 70, 1978-3). Recall simply that it was elaborated by choosing the desired distribution of speeds at $C_z = 0$ and that its configuration was calculated with the aid of an inverse method of calculation. This technique, which is widely used for airplane airfoils, is still only rarely used for helicopters. Its advantages are however considerable since it allows:

- A direct determination of excessive intrados and extrados speed and, consequently, of drag.
- A direct determination of C_{m_0} .

The profile's overall performance, as derived from tests carried out in ONERA's Modane S3 wind tunnel, are presented in figure 5 in terms of C_z max for $M_0 < 0.5$, Md_x at constant C_z for $M_0 > 0.5$, and C_{m_0} .

The objectives spelled out in the specifications were attained for Md_x at $C_z = 0$, which is 0.85, and for C_{m_0} , which is extremely low even at high Mach numbers. Concerning stationary flight, the lift/drag ratio measured in the wind tunnel at $M_0 = 0.6$ and $C_z = 0.6$ was 75. The C_z max for maneuvers were 1.27 at $M_0 = 0.3$ and 1.21 at $M_0 = 0.4$. These values are slightly lower than the objectives,

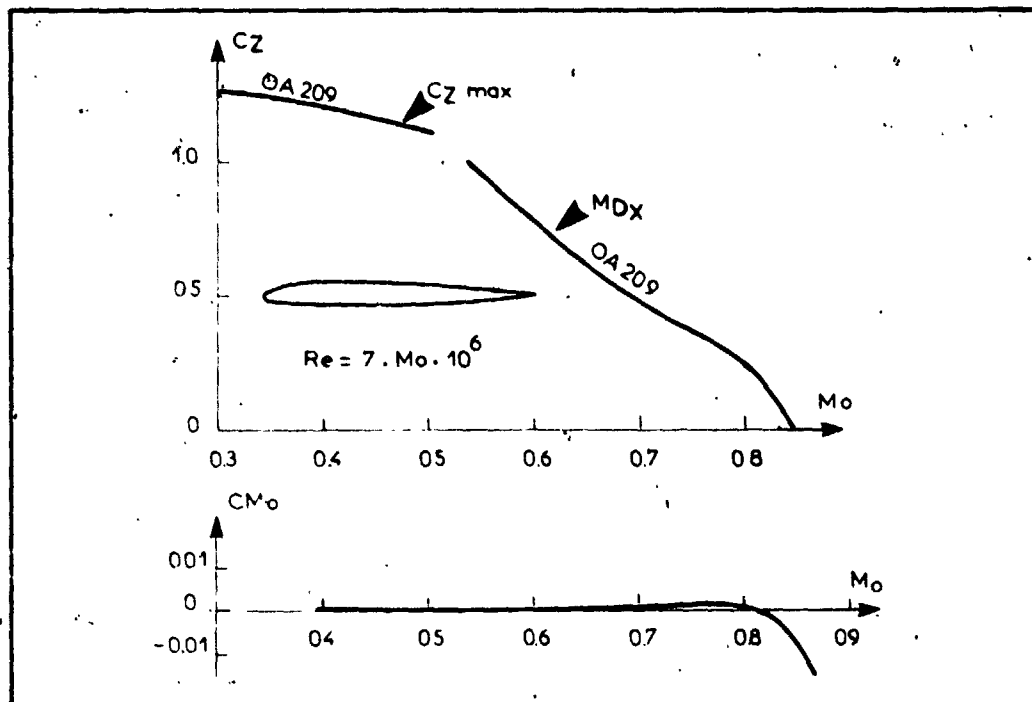


Figure 5
Profile OA 209 -- Overall Performance

but high for a profile with a 9% relative thickness.

The gains over the NACA profile are considerable in every aspect:

$$\Delta C_z \text{ max} = 0.14 \text{ at } M_o = 0.3 \text{ (+11\%)}$$

$$= 0.21 \text{ at } M_o = 0.4 \text{ (+21\%)}$$

$$\Delta M_{dx} = 0.06 \text{ at } C_z = 0$$

$$\Delta L/D = 15 \text{ at } M_o = 0.6 \text{ and } C_z = 0.6 \text{ (+25\%)}$$

Since OA 209 embodied a reasonable compromise, the profiles for the root and tip sections were geometrically derived from it.

The basic profile configuration represented by OA 209 was conserved in the tip profile OA 207 up to the primary structural member in order to maintain a good C_z max at low Mach numbers. The rear part was thinned out to obtain a profile of 7% relative thickness and a low C_x and high Md_x at $C_z = 0$.

The basic thickness relationship of OA 209 was retained for the root profile OA 212, but increased to 12%. In addition, a camber that allowed the desired C_z max to be attained while keeping C_{mo} low was sought.

Performance of the OA Profile Family

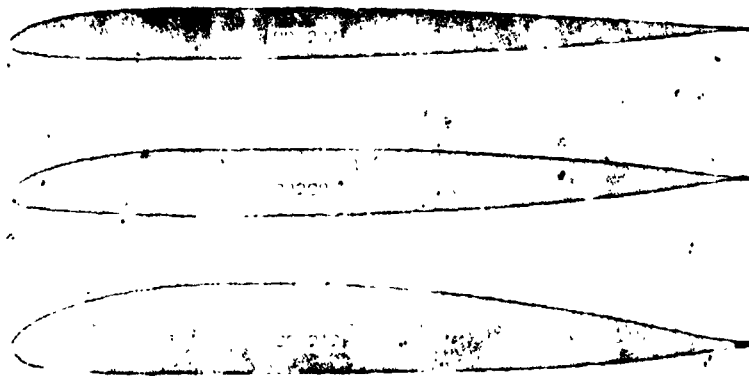


Figure 6
Design of the OA Profile Family

ORIGINAL PAGE IS
OF POOR QUALITY

Drawings of the three profiles, OA 212, OA 209, and OA 207, are presented in figure 6. Their overall performances were derived from tests carried out in the Modane S3 wind tunnel with a two-dimensional flow passing over mock-ups having a 210 mm chord. In figures 7 through 9, a comparison is made with the performance of the

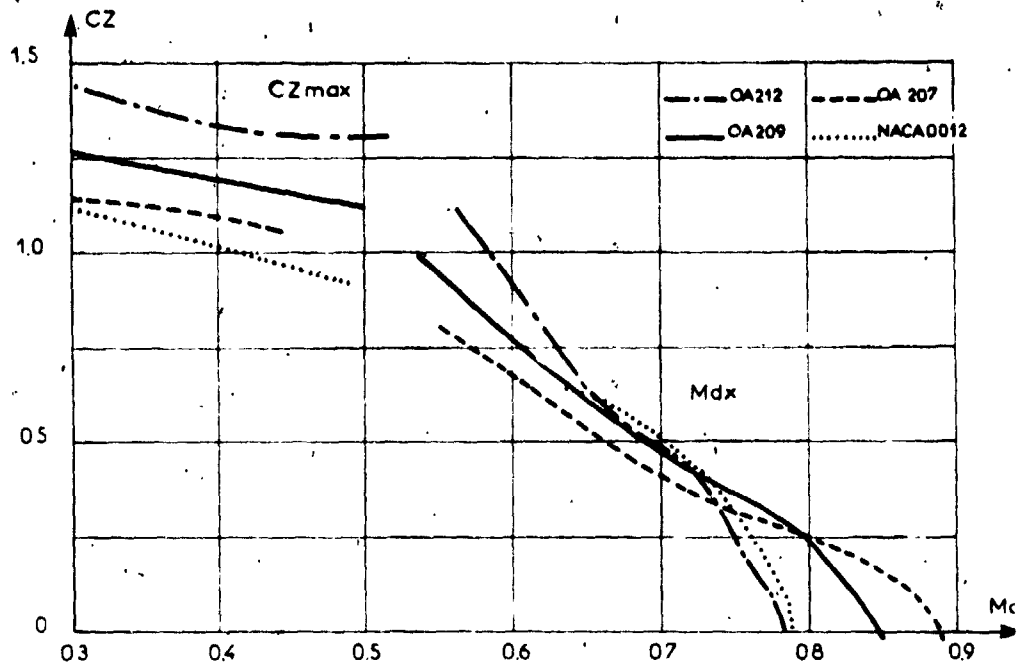


Figure 7
Overall Performance of the OA Profile Family

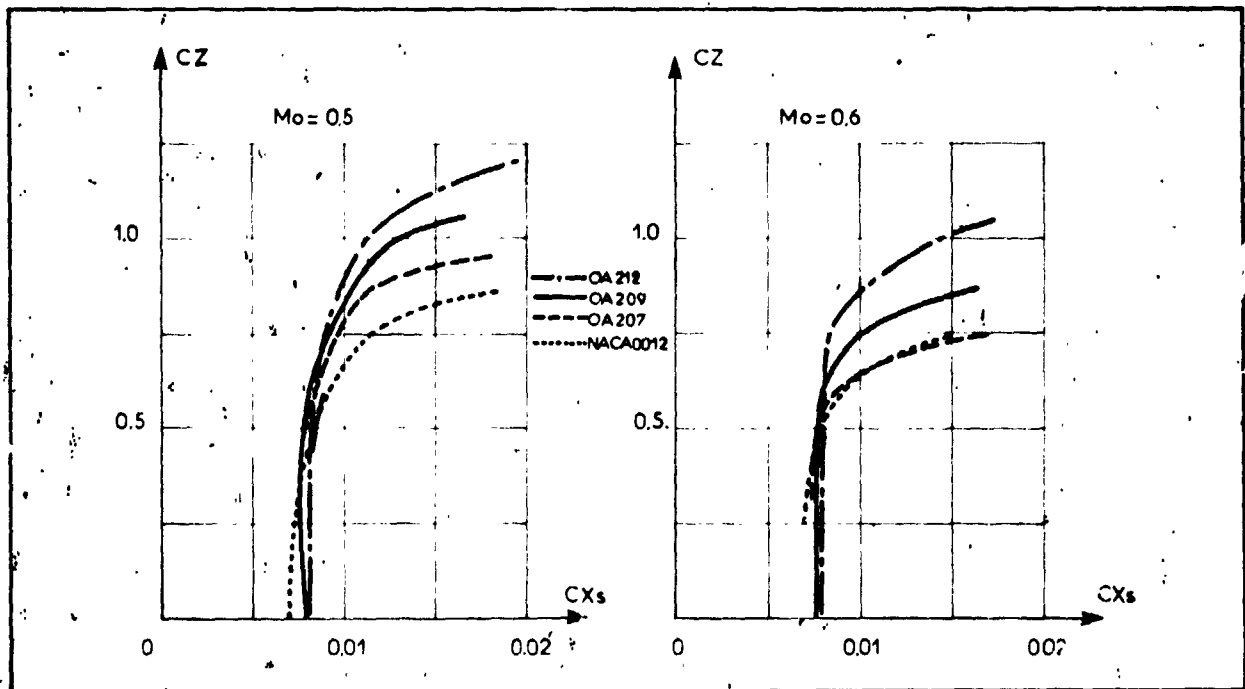


Figure 8
Polar Curves at $M_0 = 0.5$ and $M_0 = 0.6$

NACA 0012 profile under the same conditions. The overall performance characteristics are:

- C_z max for $M_0 < 0.5$ and M_{dx} at constant C_z for $M_0 > 0.5$
(figure 7)

-- Polar curves at $M_0 = 0.5$ and 0.6 (figure 8)

-- Change in C_x with Mach number at $C_z = 0$ and $C_z = 0.1$ (figure 9)

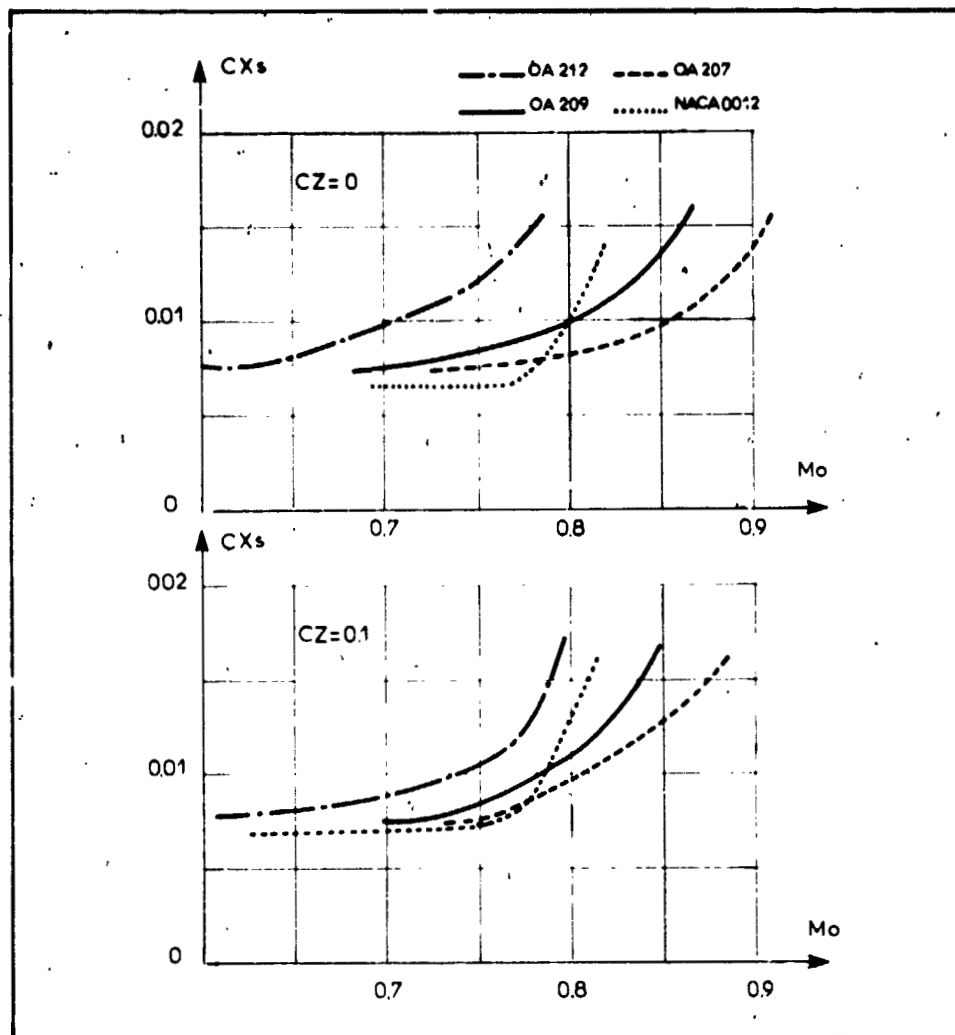


Figure 9
Change in Drag as a Function of Mach Number

There are considerable gains in C_z max compared to the NACA 0012 profile. The OA 212 profile of the same relative thickness causes an increase in C_z max of 32% at $M_0 = 0.4$ and of 44% at $M_0 = 0.5$. As for the drag divergence Mach number, the reduction in relative thickness, associated with thickness determining formulae

particularly adapted to transonic speeds, confers performances to the OA 209 and OA 207 profiles that are greatly superior to that of NACA 0012. The lift/drag ratios at $M_0 = 0.5$ and 0.6 and $C_z > 0.5$ as well as the C_x 's at high Mach numbers are equally better, but the OA family's level of precritical drag is slightly higher (figure 9). This arises from the fact that for these low C_z , cambered profiles, the transition of the boundary layer at the intrados takes place near the leading edge. For NACA 0012, it occurs at the level of impact at the tests' Reynolds number, and therefore further downwind. Aérospatiale built two four-bladed rotor mock-ups for the purpose of testing the profiles in operating conditions closer to those actually encountered by a helicopter. They were tested on the rotor testing stand in ONERA's Modane S1 wind tunnel. The 4 m diameter rotors had blades with a 140 mm chord. The first rotor had an OA 209 profile over its entire length. The second one had an OA 209 profile up to $0.8 R$. It then thinned down to an OA 207 profile at the blade tip. The tests confirmed the expected gains in comparison with NACA 0012 blades. Notably, there was:

- An increase in the figure of merit during stationary flight,
- An increase in the lift/drag ratio during forward flight, particularly under heavy load.

Based on their performance, Aérospatiale decided to equip the SA 365 N and the SA 366 G versions of the Dauphin with blades using the OA family of profiles. The performance obtained during test flights of the SA 365 N confirmed the potential gains expected on the basis of the results of two-dimensional tests on rotor mock-ups.

Conclusion

These studies, which were carried out in close collaboration with Aérospatiale, have thus led to the design of a new, high-performance rotor. Our cooperation will, of course, continue in the field of blade profiles, where progress, perhaps not as spectacular but nonetheless significant, can still be realized. Cooperation will also continue in such largely unexplored areas as:

- Blade plan form.
- Hub drag,
- Air intake efficiency,
- Anti-torque rotors.

All this activity should permit an even greater improvement of helicopter performance in the near future.