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AERODYNAMIC DESIGN OF THE AEROSPATIALE SA 365 N - DAUPHIN 2 HELICOPTER

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The SA 365N, the latest of the Dauphin family, from which the SA 366G selected by the US Coast Guard was derived, is a high performance twin engine helicopter of the new generation, specifically designed for corporate and off shore operations.

A high gross weight to empty weight ratio and a large internal fuel capacity make large payloads over long ranges possible.

A careful design of the fuselage shape and of the engine inlets has produced a fast, clean aircraft with an unusually low level of parasite drag and a very low fuel consumption, resulting in a high transport efficiency.

The main rotor, the first to be equipped with the new family of 0A2 airfoils developed in cooperation with ONERA under tight specifications, is a highly efficient rotor, both in hover where the Figure of Merit reaches 0.75 and in high speed flight with a maximum lift-to-drag ratio of 8.

These assets were demonstrated recently by the first production aircraft which made the round trip Paris-London-Paris (684 km) at the average record speed of 303 km/h, making the SA 365N the fastest helicopter in its category.

This paper discusses the theoretical and experimental work, including wind tunnel and flight tests, which led to the final design of this aircraft.

INTRODUCTION

The decision to develop the SA 365N version of the Dauphin II in 1977 was based on market studies indicating the need for a medium sized high performance helicopter specifically designed for corporate and off-shore operations (Ref. 1).

It appeared that this need could be satisfied by adapting the twin engine Dauphin SA 365C to suit specific off-shore mission requirements.

In terms of performance objectives the aim was to increase the payload-range capability of the aircraft and to keep specific fuel consumption down to a minimum.

Major changes were made in the SA 365C design in order to meet the new performance requirements :

- Fuel capacity was raised to 1140 litres with the installation of larger fuel tanks below the cabin floor. As a result, maximum range was considerably increased.
- Useful payload was optimized by keeping the empty weight of the aircraft at the lowest possible value. The structural efficiency of the overall design was thus improved and is demonstrated by the unusually low empty weight to gross weight ratio (0.5) which was achieved on the SA 365N.
- New TURBOMECA ARRIEL IC turboshaft engines and an upgraded main gearbox were installed, increasing the available power significantly.
- Important aerodynamic refinements of the airframe were made in order to reduce parasite drag and specific fuel consumption in cruise. A very low level of parasite drag was reached on the SA 365N (1.05 m2), 25 % below the SA 365C value.
- The engine air intakes were completely redesigned for improved inlet efficiency and reduced flow distortions minimizing engine installation losses and external drag.
- Finally, a new generation of rotor blades was developed and rotor design parameters selected to optimize performance in hover as well as in cruise.

AIRCRAFT DESCRIPTION

The main characteristics of the SA 365N helicopter, shown in a flight test configuration on Fig. 1, are listed below :

Airframe

Overall length (excluding main rotor blades) . . . . 11.44 m
Maximum height (top of fin) . . . . 4.010 m
Fuselage width (cabin) . . . . 2.03 m
Horizontal stabilizer span . . . . 3.21 m
Cabin volume (excluding baggage compartment) . . . 5 m3
Cargo bay volume 2.20 m3
Normal fuel tank capacity. . . . . 1140 l
Passenger capacity (including 2 crew) 14

Engines

2 Turbomeca ARRIEL 1C turboshaft engines
Maximum contingency power (2.5') . . . . 522 kW
Intermediate contingency power (30') . . . . . . 512 kW
Take off power (5') . . . . 492 kW
Maximum continuous power. . . . . 437 kW

Figure 1 : SA 365N

Transmission max continuous rating 860 kW (800 kW on main rotor shaft)

Main rotor

Composite STARFLEX rotor head and blade structure
Rotor diameter (with blade tip caps). . . . . 11.93 m
Blade chord (with trailing edge tab) . . . .0.385 (0.405) m
Number of blades 4
Solidity. 0.0822
Theoretical twist. . . . . – 10°
Shaft tilt angle (forward) . . . . 4°
Nominal speed . . . . 350 RPM
Direction of rotation (seen from above). . . . . . . clockwise

Tail rotor

FENESTRON fan in fin type
Diameter (fin). . . . . 0.90 m
Blade chord . . . . 0.0435 m
Number of blades 13
Nominal speed . . . . 4693 RPM
Direction of rotation (seen from left) . . . . clockwise

A three-view drawing is presented on **Fig. 2.**

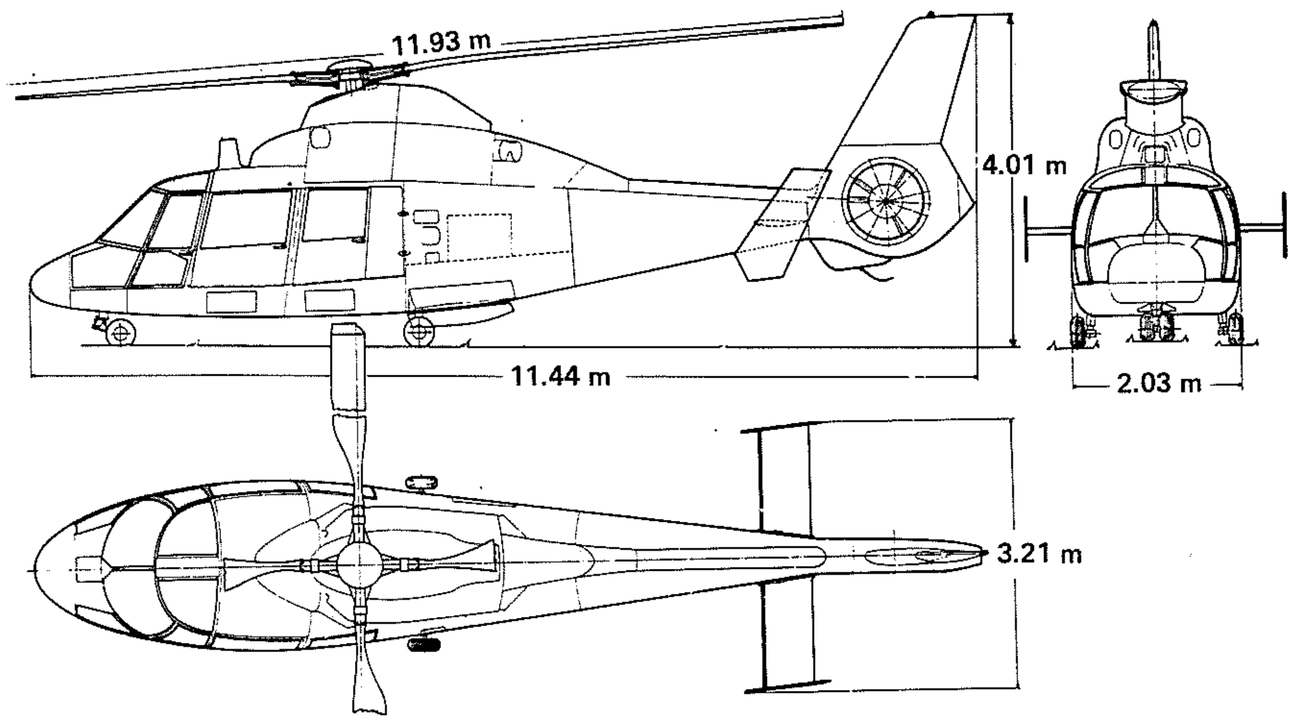


Figure 2 : SA 365N GENERAL ARRANGEMENT

AERODYNAMIC DESIGN OF THE AIRFRAME

During the development of the SA 365N, important aerodynamic refinements of the airframe were made in order to reduce parasite drag.

The general streamlining of the fuselage was improved by reducing the boattail angle at the intersection of the fuselage with the tail boom and by reshaping the blunt nose of the SA 365C into the more popular «corporate» nose shape which offers room enough to house a radar antenna and various IFR communication and navigation equipment.

The engine fairings on the SA 365N were completely redesigned to accommodate new dynamic air intakes minimizing engine installation losses in replacement of the SA 365C static inlets.

The main gearbox and engine oil-cooler air-inlet was also modified to reduce external drag.

A retractable tricycle landing gear on the SA 365N replaces the fixed landing gear of the SA 365C. Retractable footsteps for cabin access were also installed.

The emergency floatation gear on the SA 365N was integrated into the fuselage so that it does not create any additional drag when folded.

Finally, a special pylon fairing was developed during flight testing to reduce rotor head-fuselage interaction drag and attenuate the hub wake by reactivating the flow behind the hub.

Extensive wind tunnel tests, conducted during the design and development phases, have provided an accurate breakdown of drag values for the various aircraft components. **Fig. 3** presents a comparison of the SA 365C and SA 365N configurations. It shows that these aerodynamic refinements have brought a substantial reduction of parasite drag, approximately 0.35 m2 representing 25 % of the SA 365C drag value.

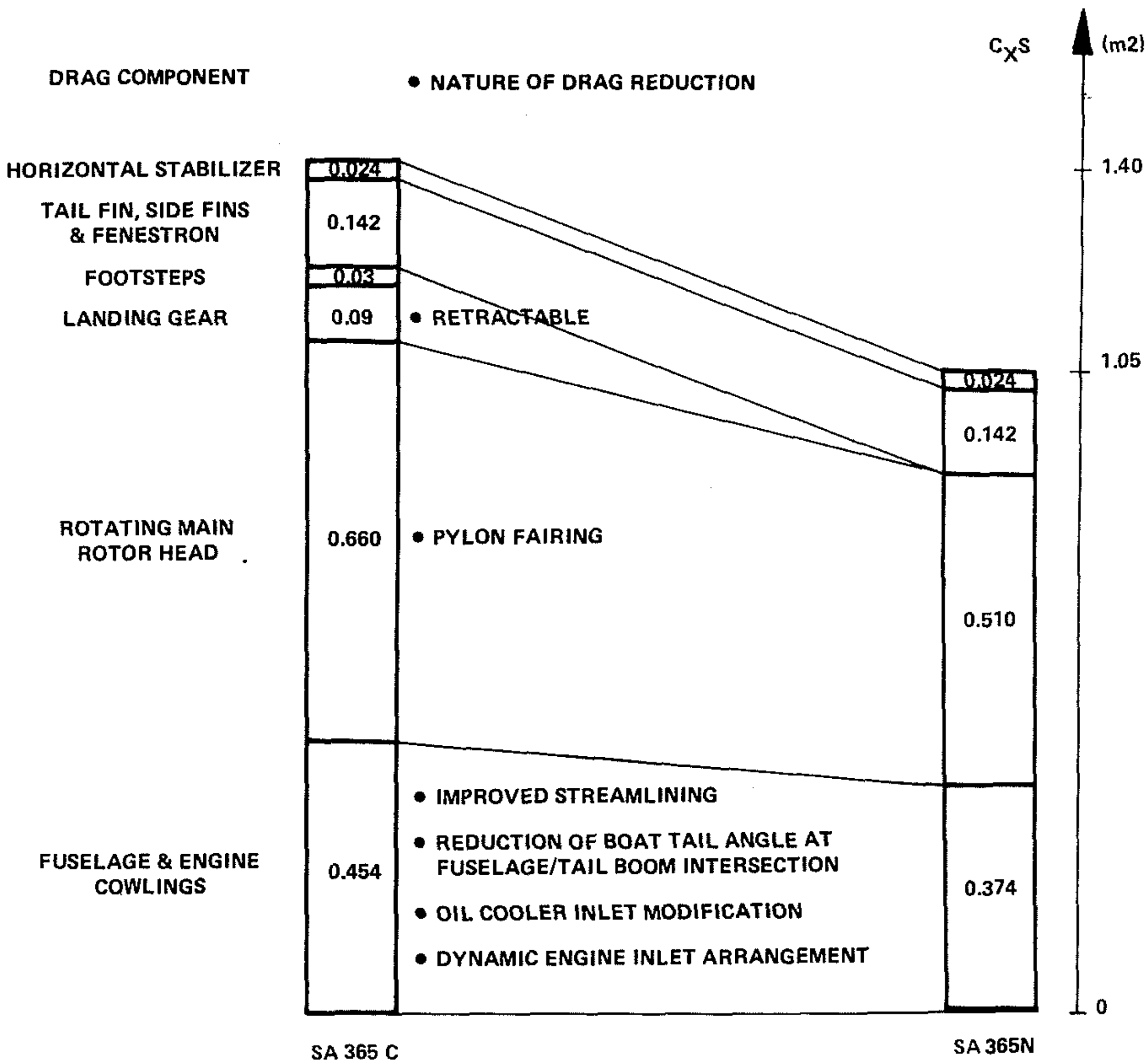


Figure 3 : AIRFRAME PARASITE DRAG REDUCTION

PYLON FAIRING DESIGN

Early in the flight test program, tail shake problems were encountered at high speed on the SA 365N prototype. It was soon recognized that the lateral kicks experienced by the crew particularily in descent regimes were associated with the wake proximity of the vertical fin.

Indeed structural vibrations were triggered off by intermittent aerodynamic loadings of the tail surfaces originating in the turbulent wake created by the main rotor head system.

At high descent rates the wake center is aligned closely with the fin due to negligible rotor flow deflection and zero trim sideslip angle (**Fig. 4**). In level flight, as the

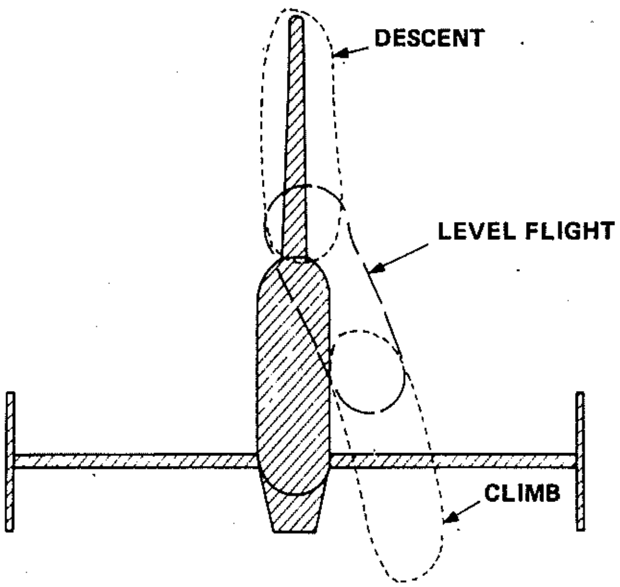


Figure 4 : ROTOR HEAD WAKE POSITION RELATIVE TO TAIL SURFACES

aerodynamic angle of attack is reduced, the rotor wake is shifted downwards relatively to the tail surfaces. Also the centre of the wake moves to the right as the wake experiences the slipstream rotation (swirl) imparted to the rotor flow by the blades in the upwind portion of the disk. As the climb regime is reached, the wake is deflected far to the right and below the vertical fin where it is no longer a problem. Indeed lateral kicks were no longer felt in this mode.

With the source of the tail shake problem identified, a research program was initiated at Aerospatiale to investigate means of modifying the wake structure and position relative to the tail surfaces.

The aim was to reduce the wake impingement on the vertical tail by moving the wake down away from the fin and by attenuating the wake turbulence.

A solution involving a complete fairing of the main rotor head system had been developped and flown in the past on a Gazelle SA 341 which broke several helicopter speed records in 1971. However this solution was rejected on the SA 365N because of unacceptable size and weight penalties. In addition the fairing hindered maintenance and was found inaesthetic.

The SA 365N pylon fairing design has evolved from hours of testing in the wind tunnel. It incorporates several features designed to depress the wake downwards and to attenuate the turbulence by introducing fresh, relatively steady air, into the core of the wake.

The top of the fairing is made up of a flat plate inclined at approximately 18° relatively to the A/C longitudinal axis. It is terminated on each side by sharp protruding lips around which tip vortices are formed. The aft portion is rounded off smoothly and dives steeply towards the rear of the engine cowlings. The sides of the pylon are contoured so as to bring the air smoothly around and past the hub.

In addition, the rotor head is covered by a hollow cap which serves to depress the most turbulent portion of the wake below the fin by bringing fresh air more efficiently over the hub.

A tuft analysis of the airflow is reproduced on **Fig. 5**.

The airstream approaching the pylon deck is deflected upwards and escapes laterally around the protruding lips into the tip vortices. These vortices also exert a suction effect on the air flowing past the sides of the pylon.

The hub cap forms a well cambered flow vane which deflects the upstream steady air over the rotor head and downwards behind the hub, where it is mixed with the turbulent wake. In producing this deflection the hub cap generates a second pair of counterrotating vortices. Thus, behind the rotor head, the flow is organized around a set of four vortices shown in the cross section view on **Fig. 5**.

Each pair of vortices produces a suction effect on the wake which, owing to the favourable pressure gradient, follows the aft portion of the pylon fairing. These vortices eventually die out before reaching the fin, approximately half way down the tail boom.

Wind tunnel tests of several pylon/hub cap configurations have shown that the major parameters affecting the wake deflection and structure are, pylon shape, plate inclination and hub cap diameter and position.

This was verified by pressure measurements of the wake, in the vicinity of the fin, made by probing the wake with an array of pitot tubes mounted on a rake, in a plane located at the junction of the fin with the tail boom. Three maps of the wake shown on **Fig. 6** demonstrate the effect of the hub cap and pylon fairing devices on the wake structure and position in descent. The baseline configuration shows a large area in the core of the wake where the dynamic pressure loss is in excess of 50 % (peak loss is 62 % at wake center). The hub cap depresses the center of the wake and slightly attenuates the dynamic pressure loss (peak loss is reduced to 56 %). The addition of the pylon fairing reduces the dynamic pressure loss and the turbulent activity in the core of the wake (peak loss is now 51 %). Wake deflection is also increased slightly.

Drag measurements of the three configurations show good correlation with the total pressure measurements. The hub cap alone has little effect on parasite drag. With the pylon fairing on the drag area is reduced by 0.15 m2.

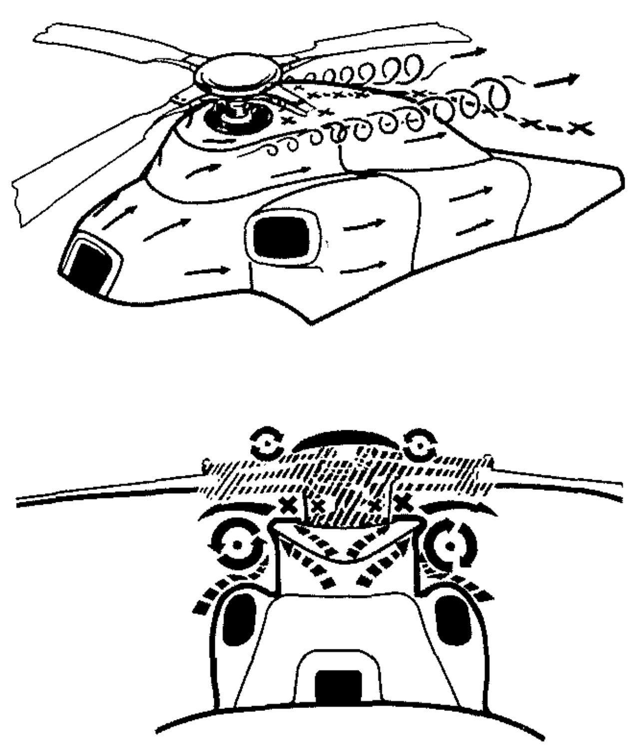


Figure 5 : PYLON FAIRING DESIGN (FLOW VISUALIZATION WIND TUNNEL TESTS)

ENGINE INLET DESIGN

The SA 365C engine cowlings and static upward facing inlets have been completly redesigned on the SA 365N. The objective was to develop aerodynamically efficient inlets characterized by a high dynamic pressure recovery in forward flight and a very low level of distortion and turbulence in all flight configurations.

The SA 365N has dynamic air intakes located on both sides of the rotor pylon, out of the rotor head wake. They are well separated from the fuselage boundary layer in order to minimize the engine power losses resulting from distortions and fluctuations in the pressure field in front of the HP compressor. The position of the intakes was selected so as to avoid reingestion of hot air from the oil-cooler flow or from the engine exhausts, which might be recirculated in hover by the main rotor, thereby causing a temperature rise in the inlets with a consequent loss of engine power.

Engine inlet area was adapted to favour cruise flight. Optimum compressor efficiency in hover requires very large engine intakes. This is contradictory with the requirement for high speed cruise, where the inlet area should be adapted to the cross-sectional area of the ingested stream-tube, as determined by airspeed and engine mass flow. The compromise adopted corresponds to a small diffusion of the stream-tube in high speed cruise (the area ratio is 0.8). However the inlet area is still small enough to prevent spillage.

Lip shape and thickness (25 % of the inlet diameter) were selected in order to maintain fully attached low drag external flow in forward flight. In hover this thickness provides a smooth acceleration of the airflow around the inner lip of the intake, followed by a mild recompression which prevents excessive boundary layer separation inside the duct.

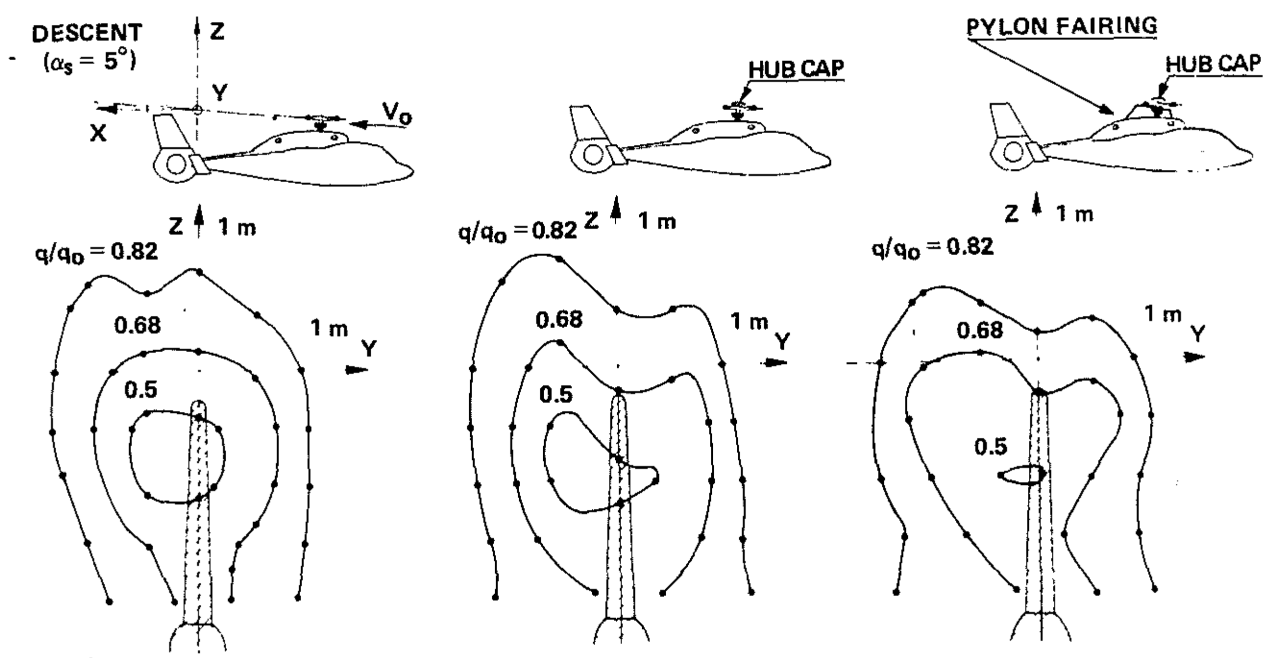


Figure 6 : MAIN ROTOR HEAD WAKE DYNAMIC PRESSURE MAP

The SA 366G Dauphin II version, equipped with the LYCOMING LTS 101 engines, has a slightly different engine inlet arrangement. The intake manifold geometry was adapted to the particular inlet scroll shape of the LYCOMING engines which is designed to provide the desired airflow distribution into the annular compressor inlet housing (the TURBOMECA ARRIEL 1C engines have an axial air intake). The inlet lip thickness was increased from 25 % to 36 % of the inlet diameter to counteract the effect of the larger diffuser on the pressure losses in hover and low speed flight.

Finally, for both configurations, duct length and shape were designed to optimize internal pressure recovery while keeping flow distortions to a minimum.

The air cooler inlet of the main gearbox and engine oil, located between the engine intakes, has also been redesigned. The inlet has been moved forward and is reduced in size to minimize drag. The new duct design incorporates a larger diffuser. The cooling air is exhausted through a converging nozzle at the rear of the pylon fairing.

During the development phase, extensive wind tunnel tests have been conducted on several engine cowling configurations to measure inlet pressure losses, distortion, and pressure fluctuations in front of the compressor (Ref. 2). The models were scaled to 1/2 size and a suction system simulated inlet flows. Temperature and pressure instrumentation was provided by static wall pressure taps and rakes installed in the ducts. Flow visualization was also used and drag measurements made of each configuration tested. These included :

- Static upward facing inlets located aft of the rotor head well, similar to those existing on the SA 365C.
- Dynamic forward facing or frontal «pitot» intakes. These were shown to be aerodynamically the most efficient. However they were finally abandonned in favor of the more aesthetically pleasing lateral intakes.
- The SA 365N lateral intakes which have a 40° bevelled inlet plane. These are slightly detached from the fuselage to avoid pressure distortions due to boundary layer ingestion.

Comparative drag measurements have shown that significant parasite drag reductions were obtained with the dynamic air intake arrangement.

The frontal «pitot» intakes produced the lowest drag value, with a drag area reduced by 0.17 m2 relative to the static inlet configuration, while the SA 365N lateral intakes resulted in a reduction of 0.09 m2 at cruise speed. These values are probably optimistic since the drag measurements were made without the protective inlet screens which have a more penalizing effect on dynamic air intakes.

Fig. 7 illustrates the deterioration of the aerodynamic efficiency of the static inlets in cruise and the dynamic pressure recovery obtained with the SA 365N inlets in

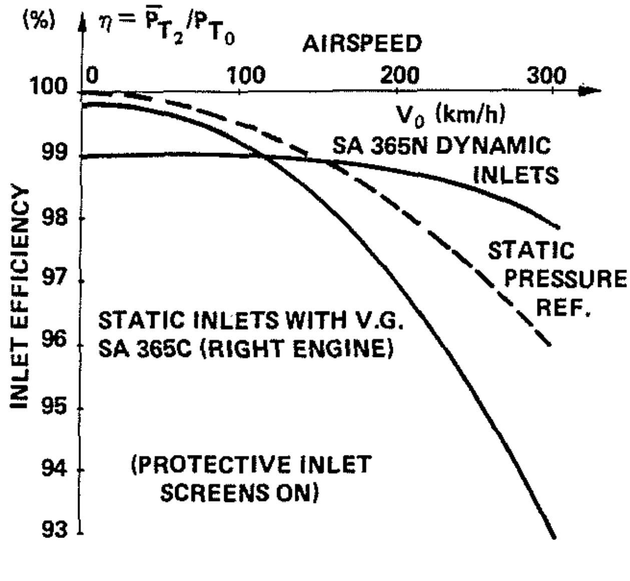


Figure 7 : ENGINE INLET EFFICIENCY VS. AIRSPEED (WIND TUNNEL TESTS)

forward flight. In addition, large distortions and fluctuations of the pressure field develop in the static inlet ducts at high speed (Fig. 8). The reverse is observed with the dynamic inlets for which the distortion coefficient of the flow (DC 60) in front of the HP compressor is reduced as airspeed is increased.

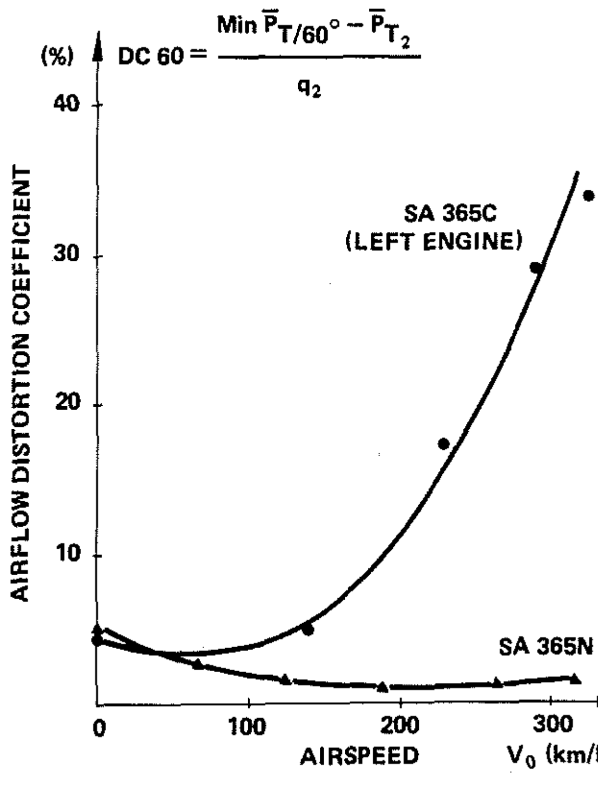


Figure 8 : AIR INTAKE DISTORSION VS. AIRSPEED (WIND TUNNEL TESTS)

These improvements in the aerodynamic design of the engine cowlings are responsible for the relatively small engine installation losses on the SA 365N in terms of available power and engine specific fuel consumption. They have a spectacular effect on single engine performance. For example, at sea level, the maximum take-off weight in FAR 29 Category A of the SA 365C with static inlets and vortex generators could be increased by 150 kg with the new engine inlet design. Engine specific fuel consumption would be reduced by 3 %, parasite drag between 4 % and 6 %, resulting in a significant fuel economy in cruise.

BLADE AIRFOIL DESIGN

The 0A2 family of airfoils was developed to improve rotor performance over designs with conventional airfoils such as NACA 0012. The goals were to increase the lift/drag ratio and increase drag divergence Mach number while maintaining low pitching moments.

The 0A2 airfoils designed for the new SA 365N and SA 366G main rotor blades are the result of advanced research undertaken by the ONERA since 1974 under Aerospatiale specifications. The purpose of this work was to design a family of modern blade profiles suited for helicopter rotor operation. Design goals were to improve the lift/drag ratio in hover flight ($M = 0.6$; $C_L = 0.6$), increase C_L at Mach 0.4 to improve maneuverability and handling under heavy loads, and increase drag divergence Mach number at low C_L for blade tip profiles. The major characteristics of these blades are summarized in **Fig. 9.**

The airfoils were generated by advanced computer design methods developed jointly by ONERA and Aerospatiale, which accurately predict the aerodynamic characteristics of a new blade profile. For each airfoil, the study involved the selection of velocity distributions giving the desired lift, drag and pitching moment characteristics. The corresponding profile shape was then calculated by an inverse method. In a subsequent phase, performance characteristics were calculated by a viscous transonic flow program.

The first profile analyzed (0A 209) was designed by selecting an upper surface velocity distribution close to Mach 1 and constant over the first 18 % of the chord to improve the lift/drag ratio at $M = 0.6$ and $C_L = 0.6$. The lower surface was modified to obtain an acceptable C_{M_O} value. A high drag divergence Mach number was achieved by using a peaky effect at approximately 30 % chord on the upper surface and a relatively flat velocity distribution in the mid chord section. The other two profiles were analyzed in similar fashion, emphasizing $C_{L_{max}}$ for 0A 212 and drag divergence Mach number for 0A 207.

All three airfoils were rigorously tested in the ONERA Modane «S3» tunnel. A comparative test was made with the NACA 0012 section used for the first generation Dauphin blades. Testing was conducted on a reduced scale model with a chord dimension of 0.21 m fitted with pressure sensors along a chordline. Tests were conducted over a Mach range and Reynolds numbers similar to those experienced by the Dauphin blade airfoil in flight. The moment and lift coefficients were obtained by integrating the pressures measured on the model ; the drag coefficient was determined from wake measurements one chord distance downstream from the airfoil.

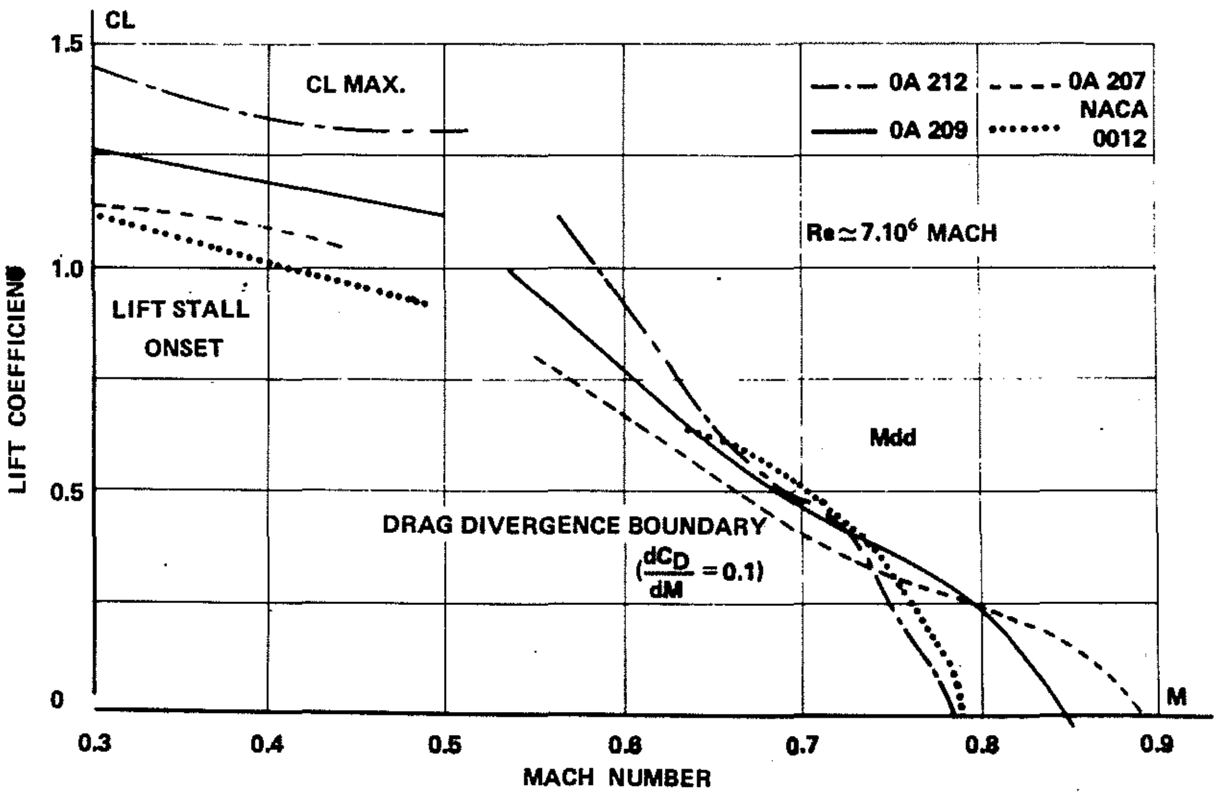
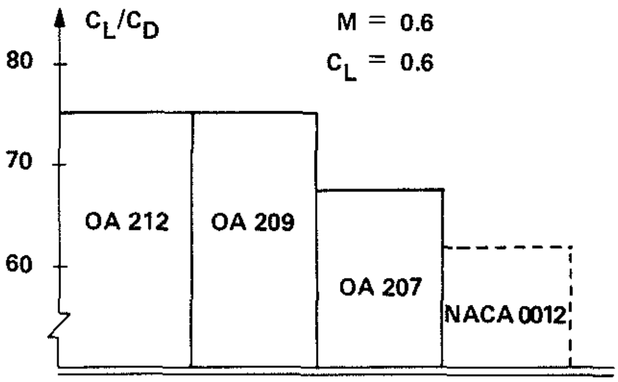


Figure 9 : 0A2 AIRFOIL MAXIMUM LIFT AND DRAG DIVERGENCE MACH NUMBER COMPARED WITH NACA 0012

These test results confirmed the improvements anticipated from design calculations. In hover flight at Mach 0.6, the lift/drag ratio obtained at C_L = 0.6 exceeded that of the NACA 0012 profile by 9 % for the 0A 207 and by 21 % for the other two new profiles, **Fig. 10.** The maximum lift/drag ratio was increased by 23 % for the 0A 209 and by 44 % for the 0A 212 at higher C_L values.

The maximum lift coefficient, C_{Lmax}, is significantly higher at Mach 0.4 ; 20 % greater for the 0A 209, and 30 % greater for the 0A 212. The drag divergence Mach numbers are noticeably improved. At zero lift, the drag divergence Mach number is 0.87 for the 0A 207 as compared to 0.8 for the NACA 0012 profile, **Fig. 9.**

These results were obtained with a very low C_{Mo} value (less than 0.01 in all cases), which is of crucial importance for the pitch link loads. Additional details of the airfoils developed are given in Reference 3.



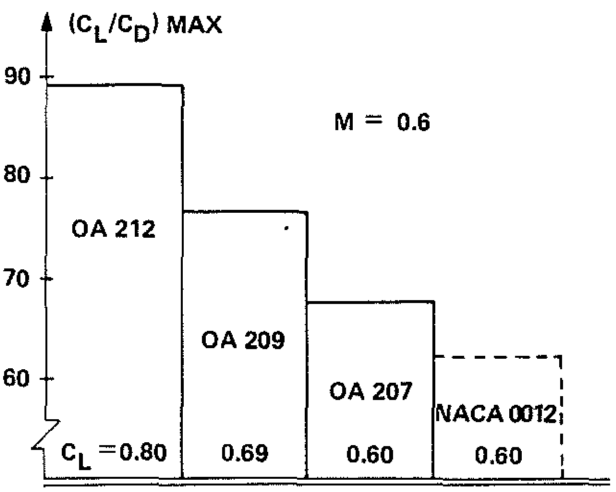


Figure 10 : OA2 AIRFOIL LIFT TO DRAG RATIO COMPARED WITH NACA 0012

ROTOR CHARACTERISTICS

To confirm the advantages expected from these new blade profiles, two model rotors incorporating 0A2 airfoils, were tested in the large «S1» wind tunnel at Modane and test results compared with those of a reference rotor generated with NACA 0012, SA 13109-1.58 and SA 13106-0.7 airfoils. The rotors were driven by two turbo-shaft engines installed in the wind tunnel **(Fig. 11).**

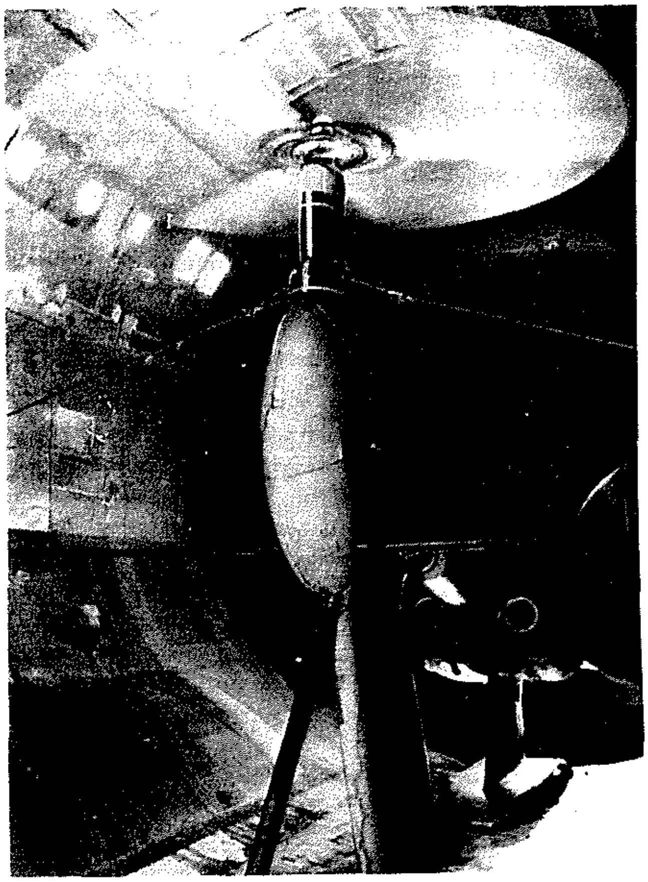


Figure 11 : ROTOR TEST AT MODANE

The tests were conducted at a tipspeed of 210 m/s and covered hover flight and advance ratios ranging from 0.2 to 0.5.

In hover, the Figure of Merit is significantly improved over the NACA 0012 rotor and forward flight results clearly showed an improvement at high thrust levels (Ref. 3 & 4). Furthermore, no Mach-related instability was observed in the test range (the maximum Mach number achieved was 0.93 at the tip of the advancing blade). The test blades were dynamically scaled with torsional stiffness close to that of an actual rotor blade.

The next phase involved constructing a full-size set of blades with a constant 0A 209 section and with blade twist and chord parameters identical to those of the first generation 0012 blades.

Flight tests were conducted in June 1977 on the SA 360/ 1001. Strictly comparative flight tests with the initial SA 360 production blades showed that the 0A 209 blades were characterized by a higher Figure of Merit value in hover (max FM = 0.75) and a greater rotor lift-to-drag ratio throughout the flight envelope.

Speed and weight gains at constant power in high altitude flight were shown to be highly significant which is consistent with the improved higher lift airfoil (Ref. 3).

During the second US Coast Guard/Navy flight test evaluation conducted in November 1978 on the SA 365C/5004, the lifting performance of the third generation OA 212/209/207 blades was substantiated when compared to earlier tests conducted in April 1978 on the same A/C equipped with NACA 0012 production blades. The A/C was fully instrumented with engine torquemeters and strain gaged shafts for main rotor and tail rotor power. Calibration was checked before and after the tests, providing the confidence required in the measured data.

Despite slight differences in twist ($-8°$ to $-10°$) and chord (365 mm to 385 mm) between the two sets of blades, the comparison of rotor Figure of Merit values plotted as a function of blade loading coefficient (**Fig. 12**) shows a noticeable improvement in rotor efficiency of the prototype OA2 blades over the NACA 0012 blades (fuselage download in hover for the SA 365C was estimated at 5 % of rotor thrust).

efficiency in hover and low blade alternating stresses and vibrations in forward flight (Ref. 5).

Rotor diameter was kept reasonably small to reduce the size and empty weight of the A/C. This leads to a relatively high disk loading of 34 kg/m2 at a gross weight of 3800 kg.

Several changes in the initial blade design were made during the flight testing phase :

- A tip cap with a 45° swept leading edge was fitted to the main rotor blades, increasing the diameter from 11.68 m to 11.93 m.
- The trailing edge tab (20 mm) was extended outboard from the 83 % radius station down to the tip of the blade, increasing the chord from 0.385 m to 0.405 m.
- Rotor speed in cruise was raised by approximately 2 % from nominal RPM to 358 RPM.

These changes produced a reduction of the alternating pitch link control loads, an improved rotor lift/drag ratio in cruise and a slight attenuation of the vibration level in forward flight which allowed the maximum VNE speed to

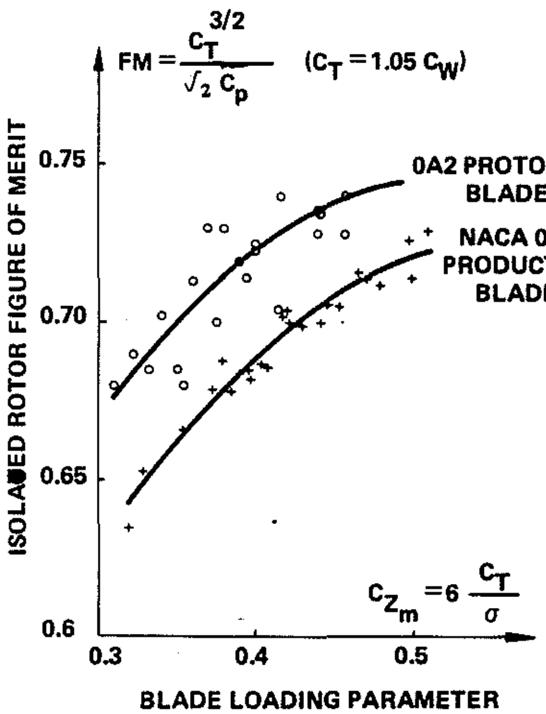


Figure 12 : ROTOR EFFICIENCY COMPARISON FROM FLIGHT TESTS

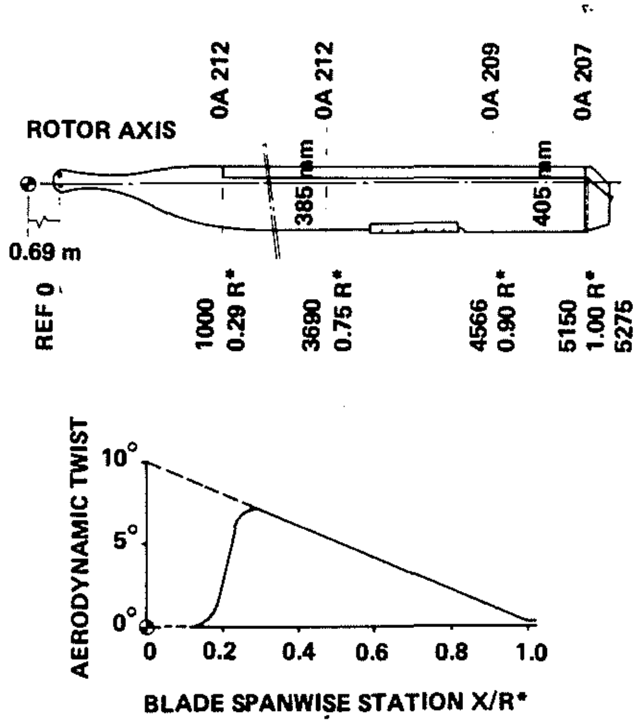


Figure 13 : MAIN ROTOR BLADE GEOMETRY

The main geometric features of the third generation SA 365N production blades are shown on **Fig. 13.**

A 12 % thick OA 212 airfoil extends from the root of the blade to the 73 % radius station and is then progressively tapered through an OA 209 airfoil (at 88 % radius) down to a 7 % thick OA 207 airfoil at the tip.

Blade twist ($-10°$ linear) was chosen, based on Aerospatiale's experience, as a compromise between high rotor

be established at 330 km/h.

The rotor lift/drag ratio (calculated from two-dimensional airfoil aerodynamic data) is shown plotted as a function of advance ratio for several blade loading parameter values on **Fig. 14.**

Results are presented for the OA2 blades and compared with conventional NACA 0012 blades of identical planform and twist.

At normal cruise speeds, maximum rotor efficiency is obtained at a relatively moderate mean blade loading coefficient of 0.4. This optimum value was selected as the nominal design blade loading parameter value of the SA 365N at maximum gross weight in standard temperature and pressure conditions.

Fig. 14 also demonstrates the improved efficiency of the 0A2 blades over the NACA 0012 blades throughout the entire flight envelope.

Differences between the two rotors are particularily significant at high advance ratios and blade loadings and are consistent with the speed and weight gains measured in high altitude flight.

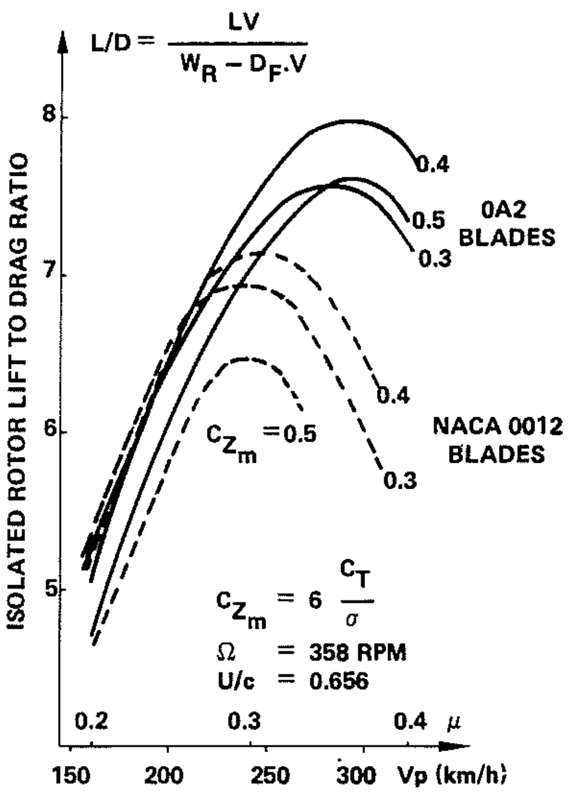


Figure 14 : OA2 ROTOR LIFT TO DRAG RATIO COMPARED WITH NACA 0012 BLADES

AIRCRAFT PERFORMANCE

Confirmation of the successful aerodynamic design of the SA 365N is reflected in the excellent performance capabilities of the aircraft, (Ref. 6).

The SA 365N is capable of FAR 29, Category A one-engine-inoperative flight at maximum gross weight at sea level and 40° C (104° F) ambient temperature.

It can cover a 500 nautical mile range with one pilot and ten passengers or 900 kg of payload, at a cruise speed of 130 to 135 knots with a normal fuel load of 900 kg.

At maximum gross weight and continuous power rating the SA 365N has a normal cruise speed of 160 knots.

CONCLUSION

The excellent performance capabilities of the SA 365N - Dauphin 2 helicopter are the result of the advanced aerodynamic design techniques applied by Aerospatiale.

The main rotor is the first to benefit from the advanced research on helicopter airfoils undertaken in cooperation with ONERA.

The exceptionally low parasite drag of the airframe and the high inlet efficiency of the engine air intakes are the result of a systematic design optimization process in the wind tunnel.

The SA 365N is a remarkably fast, clean and efficient helicopter with very long range, high payload capability and low fuel consumption which makes it very attractive to corporate and off-shore operators.

These excellent performance capabilities are undoubtedly major assets in the commercial success of this aircraft.

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